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THE DECEMBER SCIENTIFIC MONTHLY

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THE SCIENTIFIC MONTHLY

DECEMBER, 1935

SEEING THE INVISIBLE

By Dr. WALTER CLARK

EASTMAN KODAK COMPANY, ROCHESTER, N. Y.

THE adage which runs, "What the eye can't see, the heart doesn't long for," probably has proved a consoling thought to husbands whose ladies have engaged in Christmas shopping. It does not appear, however, in the phrase book of the scientist, whose great delight is to probe into and explain those things which are not obvious to his normal senses. It has been said that it is the spirit of man brooding over the stream of natural events that has given birth to science. Philosophers may argue as to whether the object of science is to explain these events of nature or merely to describe them. It is certain we should not get far in the explanation or the description if we confined our interest to those observations which we could make with the unaided eye.

For an explorer, delving into the exciting evidences of the glorious Maya civilization in the little republic of Honduras, it would be a relatively simple task to dissect the structure of one of the buildings of the old city of Copan. He would examine its external form, perhaps glorying in the beauty of its carving, and appreciate the shape and the nature of the stone blocks of which it was constructed, and learn much of the way in which they were put together. He could find out all these things by simple examination.

But suppose he were given a diamond and asked, "Please tell me how this is made"—his task would not be so easy. He would see that it was a transparent thing of beauty, its many man-shaped facets glistening in the light. But he would see little more; of its architecture he would learn nothing. His eyes could not peer into its interior and tell of its structure, of the "bricks and rafters" which went to make it the cold, hard beauty that it is. He would have to use other means more delicate than his eyes. The chemist could tell him that it was made of carbon, another form of coke, but if he wished to find out how these "bricks" of carbon were arranged he would need to use invisible x-rays. The eye, marvelous organ that it is, enabling us to see the grosser forms of objects and their colors, can not probe the deeper mysteries of matter and tell us why these objects have their shapes, and why they are so beautifully colored. The eye is relatively an insensitive thing, responding only to a very narrow range of waves in the wide gamut extending from the short cosmic rays to the long waves of radio.

Light is the messenger of the universe, bringing us the news, telling us of the existence of things, but betraying little of their inmost forms. For, the waves of light are long compared with the simple bricks, the atoms of which coarser things are made. And so we must resort to the shorter waves of x-rays, which compare in size with the atoms of matter. They

can penetrate the most opaque of things, and reveal their invisible construction. Instead of the eye, we use the photographic film, which is to x-rays what the eye is to light. The film extends our range of vision.

The marvels of to-day become the commonplaces of to-morrow. It is only thirty years since x-rays were discovered. They are now the indispensable tool of the scientist, engineer, the dentist and the surgeon. Incipient pyorrhoea, a fractured bone, a faulty casting, all reveal themselves before the penetrating rays. They are used in checking materials employed in the construction of large engineering works, machinery of transport, the construction of complex appliances inside an opaque housing, and in countless other engineering projects. Prior to the use of x-rays, faulty structures did not show their presence until failure of the defective parts occurred, resulting sometimes in loss of life. But nowadays there is little excuse for this. The value of x-rays to humanity is untold. They have been of great benefit in diagnosing tuberculosis in its early stages, and many other maladies with which man is afflicted. They have, further, revealed to the scientist the finest architecture of the simple crystals, as of salt or diamond, and the very complex structure of the felspars, of which much of our rock is made; they have shown the rearrangement of molecules which occurs when a rubber band is stretched and which gives it its elastic properties. Slowly, all materials give way before their ken.

Even more penetrating than the x-rays are the shorter so-called gamma rays of radium; these will penetrate as much as fifteen inches of steel, compared with a few inches in the case of x-rays. No apparatus is required to generate the gamma rays. They are as the life blood of radium, seeping away irrepressibly, draining it ultimately to its death. X-rays, on the other hand, require very elaborate electrical apparatus for their production. Still shorter than the gamma rays are the cosmic rays, the most penetrating we know. So far, scientists have not been able to produce or harness them, but who knows but that one day we shall convert them to our use, and what they will reveal?

But there is no need to go as far as the short x-rays to extend our range of vision. Close to the visible spectrum, just outside the range of our eyes, are the ultra-violet and the infra-red. The one, shorter in wave-length than the visible violet, is well known for its health-giving influence, in the form of the violet ray; the other, just beyond the visible red and merging into the heat waves, is used in thermal treatment when it is desired to warm up the muscles beneath the skin.

Through the microscope, the ultra-violet has shown the detailed structure of minute objects which pass unobserved when examined by visible light. It has shown the botanist that the surface of a leaf is a thin layer which absorbs very strongly, preventing entry of the short rays to damage the delicate cells beneath. It has revealed details of the cells of living matter, the minute structure of diatoms and many particulars which can not be resolved in the microscope by the longer visible light. In some extraordinarily fine work, Dr. F. F. Lucas, of the Bell Telephone Laboratories, has applied ultra-violet and blue light with a special microscope objective of unusually high aperture to the study of the structure of metals and alloys. He has photographed isolated particles which are only 200 to 300 atom diameters in size. The results have proved of great importance in the understanding of the function of heat treatment in the hardening of alloys, such as the chrome irons.

With the aid of ultra-violet photography the examiner of questioned documents becomes the despair of the forger, for he is enabled to detect the smallest

changes and to lay bare the falsifications of the most careful of criminals. The ultra-violet has also enabled the historian to reveal the original writing on palimpsests—old parchment sheets from which early writing had been removed so as to provide fresh surfaces for the pens of monks before the invention of printing—and to help the connoisseur of art to determine the authenticity of paintings concerning which there may have been some doubt.

More recently, there has been a growing interest in the study of the infra-red. This has been made possible by the discovery in the past few years of a remarkable series of dyes which can make the photographic film or plate respond to these invisible rays. Already, results of great interest have been obtained with their use. Three years ago the astronomers at Mount Wilson Observatory, using infra-red photography in the spectrograph, thought they had discovered the presence of the gas carbon dioxide gas in the atmosphere of Venus. They have now been able to show quite definitely that the planet's atmosphere contains very large quantities of the gas. The evening star is in reality a very gloomy planet. It is perpetually shrouded in a fog-like layer which has not so far been pierced. The surface of the planet has never been seen. But in the upper layers alone of its atmosphere there is about 10,000 times as much carbon dioxide as is present in the entire atmosphere of the earth. Moreover, there seems to be very little oxygen present around the planet. These facts, together with the absence of sunlight due to the shroud of clouds, indicate that there is no life, not even plant life, on its surface.

Towards the end of 1932, the planet Mars approached the earth and during the spring of 1933 it started receding, and the astronomers made an attack on it using new plates which photographic science had provided. They were interested to find out more about the constitution of its atmosphere. Without a knowledge of this, it is not possible to be sure about the opinions as to the nature of the planet's surface, nor to confirm or refute the views that there is life on it. It had long been thought that there was an atmosphere around Mars and that the atmosphere contained oxygen, essential for the support of life as we know it. Measurements now made have asserted definitely that if there is oxygen in the atmosphere of Mars, there is not more than one quarter of one per cent. of that present in the atmosphere of the earth. Such an amount could not support life of the higher forms with which we are acquainted. Is it that, after all, there is no life on Mars? Or is it a form of life which is adapted to conditions under which few living things could exist on earth? Much of the glamor of Mars has gone. Novelists can no longer thrill us with stories of Martian man, large of head and of superior intelligence. Clouds on Mars are very rare and its surface can be directly seen in the telescope. It has a desert-like appearance, and it has been suggested that oxygen, once present, has been exhausted in oxidizing the surface materials. The reddish hue of much of its surface may be due to iron oxide formed in this way.

Study of the planets more distant and less bright than Venus and Mars, although more difficult to carry out, has given results none the less startling, for in the atmospheres of these giant, cold planets has been found fairly certain evidence of the existence of the gases ammonia and methane—also discovered in the spectrograph—the former at Mount Wilson and the second at Lowell Observatory. Here is a problem for astronomer and chemist, and a rather curious one. Ammonia is a very reactive gas, consisting of nitrogen saturated with hydrogen; methane, less reactive than ammonia, and familiar as "marsh gas," consists of carbon saturated with

hydrogen. Both gases are stable. It is possible that collisions of atoms in the atmospheres of the planets have continued over vast periods of time, until eventually these most stable constituents have survived. It has been suggested that methane and ammonia are just the gases which would be expected to form if a mass of gas, having a composition like the atmosphere of the sun, were allowed to cool slowly to a very low temperature.

But the study of the infra-red has proved of great interest in very mundane things. If we gaze across the country in the direction in which we know lies a range of hills, say, forty miles away, we may not be able to see the hills at all. On some very clear days they will stand out on the skyline, steel blue with haze. On other days the haze will completely block them from our sight. The atmosphere always contains water vapor, and if this forms minute droplets on particles of dust or ions of gas which are usually present in the air, we have the appearance of haze. If the particles of moisture are bigger the haze thickens into mist or fog; our range of vision is cut down, and the outlines of distant objects are blurred, as if we were viewing them through a window of frosted glass. For these particles of moisture scatter light, just as the droplets of fat in milk scatter light, causing a turbid appearance. But they do not scatter light of all colors equally. If we view a street lamp or the sun through a haze or mist, it has an orange or red appearance, but may still appear quite sharp. This is because mist does not scatter red light nearly as effectively as it does blue or green. So that when we see the sun through a mist, the blue and green parts of the visible white light are scattered away and only the red gets through directly to our eyes. The further we get away from the blue in the spectrum, the more readily is the light transmitted by the mist, until when we reach the invisible infra-red just beyond the red end of the spectrum, it may not be scattered at all, but be transmitted quite freely.

So, if we wished to see distant objects clearly through a mist, we should do best if we could use infra-red rays. Unfortunately our eyes are not sensitive to these rays. We can, however, fall back on that substitute for the human eye, the photographic camera, and if we confine our exposures to the infra-red we can extend our range of vision and record our pictures clearly. Some exceedingly interesting results have been obtained in this way by a member of the crew of the 1934 stratosphere balloon, Captain A. W. Stevens, of the U. S. Army Air Corps, flying a plane in the region of the Andes in South America and in the direction of the Rocky Mountains in this hemisphere. In 1931, Captain Stevens, from a distance of 310 miles, photographed the peak of Aconcagua in the Andes. The mountain, of course, was quite invisible to the photographer's eye, and in order to ensure getting it in his picture he had to orient his camera by compass. This photograph excited a lot of interest because it showed the line of haze over the Pampas as curved, owing to the curvature of the earth—the first time that this had been photographed. Somewhat later, in 1932, Captain Stevens photographed objects at still greater distances, the subject of particular interest being Mount Shasta, which was no less than 331 miles from the camera. There is really no limit to the distance over which objects can now be photographed, except that imposed by their size and by the curvature of the earth.

More recently, there appeared in the *National Geographic Magazine* one of the most remarkable photographs ever taken. This was also the work of Captain Stevens, and showed the whole of greater New York and much surrounding country in surprising clarity of detail with complete elimination of the haze. It was made not using invisible infra-red rays, but with the deep red rays near the ex-

treme of the visible spectrum. There is much aerial survey work done, both in time of peace as well as during war. It enables maps to be constructed accurately at a cost very much less than when the normal methods of surveying from land are employed. However, when the photographs are taken from such a height that there is no blurring due to motion of the airplane and that sufficient territory appears in the picture, atmospheric haze invariably spoils the definition of detail in the photograph. Such pictures are, therefore, always made with the more penetrating longer red light of the visible spectrum or, more recently, with the region of the infra-red near to the end of the visible red.

It has been suggested that the use of infra-red photography might be of value in enabling sailors to navigate ships with safety in dense fogs at sea, and infra-red cameras have been installed on a number of ships. It is known, however, from theoretical grounds, and practical results have confirmed it, that no increased penetration could be obtained in the case of a fog which was a danger to navigation. But, even if such photographs can not be used for navigation in all kinds of fog, a fleet of airplanes equipped with infra-red cameras for penetrating the lighter haze which cuts down visibility could be of real value as a scouting arm attached to a battle fleet in time of war.

In the later years of the last century, Captain Abney, a foremost British photographic investigator, produced some plates which were sensitive to the infra-red. His results are of historical interest only, because his plates are very difficult to make and use. He did, however, succeed in photographing the spectrum of the sun to a wave-length beyond 10,000 Å., an achievement which it has only been possible to repeat in recent years. The present limit is 13,536 Å., recorded of late by Babcock of Mount Wilson Observatory using some remarkable plates prepared by the Kodak Research Laboratories. As a result of his experiences with the infra-red, however, Abney suggested that it might be possible to photograph a kettle of boiling water in the dark, using the heat rays given off from it. So far this has not been done, but using modern plates, it has been a relatively simple matter to photograph bodies at a somewhat higher temperature than boiling water, using the heat rays which are quite invisible to the eye. For instance, an electric flatiron can be photographed in total darkness, making use of the invisible waves radiated by it.

Still more interesting is the fact that photographs have been made of a plaster bust in the dark, using two flatirons instead of the lamps which would be used in taking an ordinary photograph. Of course, it would be very unpleasant for a human subject to be subjected to the heat from two irons while his photograph was being made. (We can discredit the schoolboy's story that Henry VIII used a flatiron when he "pressed his suit on Anne Boleyn.") It was for this reason that the plaster cast was used. The ordinary electric lamp, however, gives off a relatively large proportion of its rays in the invisible infra-red. So, if it were possible to screen lamps with filters which do not let through any visible light, and use plates sensitive to the infra-red, it should be possible to photograph people in the dark without subjecting them to much physical discomfort. This has been done on several occasions with very short exposures; even motion pictures have been made in complete darkness.

Portraits by infra-red rays are not characterized by any degree of beauty. In them the flesh appears chalky, the red lips come out light, the eyes appear as black circles, and all lines in the face are enormously exaggerated. Effects such as this are due to the peculiar way in which materials reflect and transmit the infra-red. It is not possible to tell from the appearance of an object by visible

light how it will reflect the invisible radiations. By infra-red, for instance, there is a practically complete elimination of the stripes and the background of the stars of the United States flag. A series of pieces of black dyed cloth can be selected which look equally black to the eye, but in the infra-red photograph they appear as a scale of grays ranging from white to black. It is possible to photograph a Negro in a black suit and in the print find he looks like a man with fair skin in a Palm Beach suit! In an infra-red picture of a landscape the leaves of the trees look very light, giving the trees the appearance of being covered with snow. This effect is obtained because the chlorophyll in the leaves, which gives them their dark green color because it absorbs blue and particularly red light, reflects the infra-red very freely.

Now this characteristic which many materials possess, of reflecting and transmitting the infra-red much more freely than they do visible light, has given some results of very considerable interest. Suppose, for instance, a photograph is made of a man's chest by infra-red. The picture will differ very markedly from a normal photograph and from what is seen by the eye. The veins will be clearly visible in it. These veins are actually invisible to the eye because they are buried beneath the layer of skin. A result such as this might be expected, if it were remembered that infra-red rays are used in therapy for warming up the muscles below the skin. The fact that they can be used for this purpose shows that they can penetrate skin and flesh. It will immediately be said, "Well, then, why can not we use infra-red pictures as a means of medical diagnosis, to show incipient afflictions having their origins below the skin?" This has already been done, and is being extensively studied at the moment, and the results are of great interest. Varicose veins and congestion of the capillaries can be seen, and the study of skin lesions is being actively investigated. It appears that here we have a tool which may one day prove of considerable value to the doctor. Would it not be of importance if we could show the presence of diseases before the skin took on its characteristic appearance? Certain diseases of plants have already been diagnosed in their early stages in this way by infra-red photography of the leaves.

Among the old works in the Huntington Library at San Marino, California, is a copy of De Bry's "Voyages." Some passages in this work were considered objectionable by the censors of the Spanish Inquisition, who deleted them in the year 1632 with a layer of black ink—so thick that it can in places be felt as a ridge by the finger—and completely obliterating the offending passages. Dr. L. Bendikson, of the Huntington Library, heard of the success with which the astronomers at Mount Wilson Observatory had been using infra-red plates, and borrowed a few to see if they would help him in deciphering the old books. He had already tried ultra-violet without success. To his delight he found that infra-red could penetrate the censorial ink, showing up the underlying printed matter as if the inquisitor had never existed. It was fortunate that the censor knew nothing of the properties of his inks in the infra-red, or he might have chosen one having the same characteristics as the ink used for printing the book, and our librarian would have been foiled.

Dr. Bendikson, prompted by his success in this instance, then turned his attention to some of the documents which had been badly charred by fire in the disaster which occurred in the New York State Capitol at Albany more than twenty years ago, causing serious losses to the State Library. Here again, he succeeded in deciphering passages which had been rendered quite illegible by the fire.

There is another way of deciphering

charred documents, which was worked out in the Bureau of Standards some years ago. In this case, the charred page is merely put in contact with a photographic plate and left in the dark for several weeks. On developing the plate a negative image of the original writing is found from which prints can be made and the writing read with surprising clarity. This method has been used with success by a number of examiners of questioned documents, mainly for deciphering important financial documents such as ledgers, bonds and checks which have been rendered illegible by charring.

During the course of the excavations which have been going on in Herculaneum in Italy, many old rolls of Roman papyri have been discovered, which were completely charred during the eruption of Mount Vesuvius which overwhelmed the city. These charred rolls are so fragile that it requires exceeding care to open them out flat so that they can be studied. But when this is done it is found that the old writing is practically invisible. By very skilful arrangement of lighting and astute methods of increasing contrast photographically, however, Signor Ferdinando Lembo of Naples has succeeded in photographing them in such a way that the records have been able to be read with ease by the historian.

So far we have considered mainly those things which are invisible because the radiations which announce their presence are outside the range to which the eye can respond. There are other things, however, which emit light of such a low intensity that the eye can not see them, and there are events which take place so rapidly that our senses are unable to arrest any impression of them. These rightly fall under the heading of the invisible.

The photographic plate possesses an attribute additional to those already mentioned, which gives it another advantage over the eye. It can go on building up an impression as long as it is exposed, so that eventually those things which are so weak as to give no record when exposed for a short time, can be made to build up an image of any desired intensity. The eye can not do this. If a source of light is so weak as to be below the threshold of sensitivity of the eye, it remains invisible however long we look at it.

Without photography, our knowledge of the universe would be but a very small fraction of what it actually is, even if we consider merely the numbers of stars and ignore what we have learned of their constitution; for many of them are so weak as to be quite invisible, even in the highest power telescope. Suppose we were photographing a portion of the constellation of Orion, and that in making it, two exposures were given, one one hundred times as much as the other. If the shorter exposure showed a few of the most prominent stars, the longer one would show a very large number of stars large and small. Perhaps at the bottom of the photograph would be the great first magnitude blue star, Rigal; above it the Sword Belt, and in the curve of the sword an object which does not form a sharp image on the photographic plate. It is the great nebula of Orion, one of the most wonderful objects in the sky. Photographed in the highest power of the telescope, in the middle of the nebula is a great dim cloud of light, in the words of Sir James Jeans, "looking like drifting masses of smoke such as one sees when a house or a haystack is on fire. And, indeed, they are, so to speak, only the smoke of our own star-city, lighted up by the lights of our own star-city; they are the wisps and clouds of dust and luminous gas stretching from star to star within the confines of the Milky Way, and forming light and dark patches against the sky, much as the smoke and flame of an ordinary fire form light and dark patches against the sky." In the way that the photographer has been able to penetrate the haze on earth, revealing

the detail of his distant landscape, so the astronomer has been able to penetrate the haze of his nebulae, revealing through them images of faint stars invisible in a usual photograph, masked by the luminous gases.

At night time, in the headlights of our cars, we see repeated flashes, bright points of light, appearing and disappearing, but moving rapidly with respect to us, and giving no impression of well-defined form. The state of our radiator and windshield after the journey shows that we were observing the flight of insects. If we were able to arrest them at any one part of their path, and fix a stationary image of them on the eye for a short time, we might be able to recognize their form. If we can not recognize a flying insect, still less can we identify more rapidly moving objects, such as a golf ball or the bullet fired from a revolver. But, here again, photography comes to our aid, and provides us with a means of arresting their rapid flight.

A golf ball, struck by an average player in making a drive, leaves the club at a speed of about 180 feet a second. Now, the shortest exposure usually available on the best of photographic cameras, such as those used by press photographers, is one thousandth of a second. In this short interval of time the golf ball moves two inches, and in the photograph it would appear as a white blur two inches long. We can tolerate a movement of the ball of only about 1/50th of an inch while the exposure is being made. With this a reasonably sharp picture can be obtained. The ball, however, moves 1/50th of an inch in 1/200,000 part of a second, an exceedingly short time, quite unattainable with a mechanical shutter on a camera. Even if it were attainable we should be faced with the problem of providing enough light to give a good photograph in such a short time. Fortunately, there are means available which can produce very bright flashes of light of exceedingly short duration. One of these is the electric spark; the other is a discharge through a mercury arc lamp. Using this second method Edgerton, of the Massachusetts Institute of Technology, has made a series of very interesting studies of high-speed phenomena. One of his photographs shows a golf club at the moment of its impact with the ball. The ball, before it has moved from the tee, is clearly very considerably compressed, flattened at the side in contact with the club. The club and ball travel together for a distance not exceeding one half of an inch, the ball then races ahead of the club, flattening next in a direction at right angles to its former direction of compression, then oscillating somewhat, and all the time revolving backwards at a rate of 5,000 revolutions a minute. Without photographs such as these, taken in 1/200,000 of a second, we could learn little of the mechanics of the flight of the ball. (At the same time such knowledge is not calculated to improve the standard of the player.)

By using the newly developed technique of high-speed photography, it is possible to study the movement of flame in mixtures of explosive gases. Such studies are of immense importance in those fields where it is desired to eliminate explosions, as in the mining industry, or where it is deliberately desired to use them, as in the design of internal combustion engines. One of the earliest scientific applications of photography was in the photography of flame, some 50 years ago, shortly after the photographic material of the general type we now use was introduced. With the development of high sensitivity and other properties in photographic plates and films, and new lenses having high apertures, enormous progress has been made in the study of explosions. There are two ways of studying flames photographically. In one a series of snapshots of the flame is made in succession at very short intervals on a plate or film, showing consecu-

tive stages in the propagation. In the other method, a plate or film is made to move rapidly in a direction at right angles to the path of the explosion, an image of the flame being focussed on the plate or film by a lens. A trace is obtained, from the slope of which the speed of the flame can be calculated.

In an explosion in a mixture of gases, the flame can travel at velocities varying from 0.3 to 3,500 meters per second, or, say, one half to seven thousand miles an hour. But whatever the velocity, the rate and characteristics of the explosion can now be satisfactorily studied. In the hands of Fraser, of the University of London, and Ellis, of the University of Cambridge, extremely valuable data have been collected in this way on the course of explosions in mixtures of gases, and particularly, the behavior before and after detonation.

Perhaps the most fascinating of all examples of high-speed photography is that of the photography of bullets propelled from firearms. The earliest work of this kind was carried out by Professor C. V. Boys in England, but the best photographs are those made a few years ago by the late Philip Quayle at the Bureau of Standards. In the system employed an intense electric spark of very short duration is used to take the picture, although the method of taking it is not as simple as might appear. The bullet travels at a rate of some half a mile a second, and the camera has to get a glimpse of it before it passes from its field of view; elaborate electrical apparatus is necessary to ensure this, and to provide the two millionth of a second flash necessary to give a glimpse of the bullet's flight and record its image on the plate.

A series of photographs of a bullet being fired from the muzzle of a revolver is very instructive. When the bullet is just clear of the muzzle, the gases which have leaked past it, and the powder particles which were left in the barrel after the previous discharge, are seen ahead of it. The sound wave generated by the release of the gas, and which is audible as the familiar crack, is just being formed. When the bullet is 1¼ inches out of the muzzle the sound wave has grown to 3 inches. The bullet is no longer being accelerated by the expanding gases. Both bullet and the sound wave move on, until soon the bullet passes clearly through the wave and flies ahead of it. The projectile, now in free air away from the muzzle, generates sound waves itself, due to its head, its base and the rifling marks; they are like the waves on the sea, the wake of a speed boat or a fast-moving liner, and cause the whine of the bullet in flight. Information obtained in this way has proved of great help in studying the phenomena attending the discharge of firearms. It is but one more illustration of the application of photography to aiding the understanding of technical problems, and in enabling us to "see the invisible."

And so we see how photography enlarges the scope of the eye, enabling us to study events which take place too rapidly to be followed in detail, or which are not bright enough to be seen; stretching our vision beyond the limits of our ken to the realm of radiations to which our senses will not of themselves respond. Before the eye of the camera the universe unfolds, and the secrets of matter are slowly giving way. This is the age of progress and in it the century-old art is playing a prominent part. We are in an era of great scientific discovery, which has come about largely because of the insatiable curiosity of the scientist. Must we not change our adage, and say of him: "What the eye can't see, the heart *does* long for?"

NUMBER AND CLEAR THINKING

AN ASPECT OF HUMAN CULTURE

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THE earliest impacts of number on human culture, that is, on the intellectual and esthetic content of civilization, are lost from our view in a prehistoric past so distant as to deny all hope of recovering precise facts concerning them.

It is doubtless true that a certain number-sense was developed in human history long before numbers made their explicit appearance. A child may well observe that one object from a collection of four similar objects was removed while he was not looking, though he is still unable to form such a concept as is involved in the words three and four. It appears, in fact, that some animals have developed a certain number-sense. A bird may continue with a nest when one of four eggs is removed but desert it if two are taken.

He who first observed the common element in *two* days and *two* stones, took a great step forward in the development of human culture, going well beyond what the preman saw who first observed that two stones might kill a snake while one would not. To recognize that property of two collections from which it arises that they have the same number of elements requires no little power of perceiving abstractions. But these preliminary stages in the development of the number concept are lost in the mists of prehistory.

Primitive cultures still exist in which there is only a very partial development of the number concept. It is tempting to suppose that acquaintance with these may throw some important light on the history which has culminated in our own acknowledge of numbers. But to make such a supposition is merely to speculate: the facts are unknown. And there is indeed an element which might well cause us to hesitate. It appears probable that the total history of primitive cultures is chronologically as long as our own, even though it seems to us reasonable to suppose that it is not so rich in details. It would follow, then, that the development of those cultures which are still primitive has proceeded at a different rate from ours; and this fact is undoubtedly significant. It is therefore unsafe to read our knowledge of present-day primitive cultures into our own history.

It is clear that considerable progress with the understanding of number must have been made long before the invention of any written language suitable for recording the early steps. The first glimpses into the literary records of human culture reveal number as already on the scene; and it is playing a rôle which it could have assumed only after a long preceding historical development. The positive knowledge which we can create through the investigation of ancient remains has already lost much of its precision when we press back as far as 4000 B.C.; and literary documents of any clear adequacy are first to be found only at later dates. But a long and flourishing mathematical and architectural development must already have taken place before the ancient Egyptians could have brought into existence the magnificent structures of the third millennium before Christ. And far beyond that must our mental vision pierce into the darkness to see the beginnings of

that development which enabled the ancient Babylonians to deal effectively with square numbers and with sexagesimal fractions.

Even when records begin to appear there is some evidence that the most active mental experiences with numbers were not recorded. In the computations of the ancients, "head reckoning," or mental arithmetic, was apparently more widely employed than written work. It is known that such mental reckoning was required of students in some of the ancient schools. An extant Egyptian document from about 1300 B.C. contains an admonition to pupils running about as follows: "When you are computing silently, let no spoken word be heard." (But the ancient Egyptians are not known to have raised the behavioristic question whether the mind or the larynx was computing.) It is evident that the wide-spread use of this head reckoning would tend to decrease such documentary evidence for the number processes employed as might persist to our own day.

We must pass over the remaining aspects of the beginnings of things, not even taking time for such an interesting and remarkable document as the Ahmes papyrus from Egypt with the intriguing title, "Directions for Obtaining the Knowledge of all Dark Things"; we remark merely that this ancient treatise, devoted largely to properties of numbers, indicates by its title that there is nothing novel in the subject "Number and Clear Thinking"—the theme is hoary with millennial wisdom.

It is with Pythagoras (sixth century B.C.) and the Pythagoreans that the concept of number first comes into explicit precise verifiable relations with the problem of clear thinking. The historically important part of the work of Pythagoras, though preceded by a period rich in experience, begins with his migration to Crotona in Italy about the year 529 B.C. Here he became the center of a great organization having in some respects the character of a religious brotherhood or an association for the moral reformation of society. The intellectual advances made by this school arose in the atmosphere of moral earnestness and social reform. But the scientific doctrines themselves appear to have had no intimate connection with the religious mysticism of the society or the rules of conduct of the brotherhood.

The central aspect of Pythagorean philosophy lies in its recognition of the numerical and mathematical relations of things. In the earlier times the dim realization of these abstract considerations led to the assertion of the essential existence of numbers as the causes of phenomena or of the still more specific proposition that number is the essence of everything. Aristotle tells us: "The Pythagoreans seem to have looked upon number as the principle and, so to speak, the matter of which existences consist." Again he says: "They supposed the elements of numbers to be the elements of existence, and pronounced the whole heaven to be harmony and number." Philolaus, a later Pythagorean, says: "Number is great and perfect and omnipotent, and the principle and guide of divine and human life." Fantastical this may be (and perhaps removed from clear thinking) but nevertheless it is prompted by the underlying truth that "it is number or definite mathematical relation that separates one thing from another and so in a sense makes them things." Thus number was recognized by the Pythagoreans as the principle of order, the principle by which the world, instead of being a chaos, becomes a cosmos. The chief grounds for their theory they found in the regular movements of the heavenly bodies and in the harmony of musical sounds, dependent upon the arithmetical ratios of small integers.

The theories of the Pythagoreans have

their reverberations even up to modern times. Let us illustrate with quotations from English literature:

Billingsley (1570): "Nomber compasseth all thinges, and is . . . the being and very essence of all thinges."

Argyll (1857): "These laws of number and proportion pervade all Nature."

Steele, *Spectator*, No. 174: "Numbers are so much the measure of everything that is valuable that it is not possible to demonstrate the success of any action or the prudence of any undertaking without them."

Thus the doctrine persists in literature, even if it has become somewhat attenuated. Moreover, it also has a certain precarious existence in everyday living and conversation. The possession of precise information about a person's ability, character, intentions, psychological disposition and even moral integrity, serving to identify him (in essence and substance) as belonging to a certain type, may be indicated by a succinct and expressive colloquialism, redolent of Pythagoras, namely, "I've got your number."

When we are told how Pythagoras insisted that mathematical objects, such as numbers and shapes, are the ultimate stuff out of which the real entities of experience are constructed, we may at first feel that the idea is crude or indeed silly. But when we recognize that he is reaching toward the proposition that to know something perfectly general about the elements in any situation is to know many other equally general concepts which are exemplified in that situation, and when we realize that the history of thought has proved the presence of this general truth in these speculations, we begin to see in Pythagoras the first man to get any clear grasp of a general principle which has exerted a profound influence upon clear thinking for more than two millennia. He was insisting upon the importance of the utmost generality in reasoning and he saw the essential character of number as a necessary element in the construction of intellectual tools for understanding nature.

The intrinsic importance of Pythagoras necessarily lies primarily in his own thought; but the influence of any thinker owes something to chance. In order to be influential historically one's work must be taken up effectively by later thinkers. Pythagoras was fortunate in that his speculations germinated in the mind of no less a thinker than Plato. The Platonic world of ideas was developed from the Pythagorean doctrine that number lies at the base of all things in the real world. By arranging numbers in patterns of dots, according to the Greek fashion, one begins to associate shapes with numbers; and thus Pythagoras was led to include form in connection with his doctrine of number as underlying all things. "So today," says Whitehead, "when Einstein and his followers proclaim that physical facts, such as gravitation, are to be construed as exhibitions of local peculiarities of spatio-temporal properties, they are following the pure Pythagorean tradition."

Between the epoch from Pythagoras to Plato and that of modern scientific discovery stretches a long period of development in which the human mind, building in each generation on the intellectual heritage from the past, has moved from one stage of conquest to another, very slowly at times, but with astonishing swiftness in recent generations. Great scientists, great philosophers, great mathematicians have sought to realize in some measure the abstract generality and inclusiveness foreshadowed in the speculations of Pythagoras concerning the nature of number and the nature of things. If Pythagoras could have foreseen the issue he would have had one additional justification for the excitement which prevailed in his brotherhood.

There is another aspect of Pytha-

gorean thinking about number which I must bring to your attention, owing to the important bearing which it has (in another direction) upon the problem of exact thought. The discovery in question has had a profound influence on the development of the modern theory of irrational numbers. To prepare the way for presenting this discovery let us first say a few words about the early Greek conception of number and of the place of number in a theory of measurement.

The early Greeks did not think of one as a number: to them it was the unit out of which number is generated, while a number was always considered as a collection of units. Thus for them numbers were the positive integers 2, 3, 4, . . . Some of the later Greeks would sometimes speak of one as a number. What we would denote by a fractional number, such as $\frac{3}{4}$, the Greeks would subsume under the notion of ratio. The number speculations of Pythagoras would therefore be confined to the positive integers 2, 3, 4, . . . , with the unit 1 playing a special rôle of its own.

Measurement, in its primary aspect, consists essentially in the comparison of two given lengths. The Pythagoreans inclined, almost instinctively, it would seem, to express this comparison by aid of a common unit of length which would be contained in each of the given lengths an exact integral number of times. To get the effect of their point of view we might think of two lengths, one of 3 and $\frac{1}{2}$ inches and one of 2 and $\frac{1}{12}$ inches, for instance, as measured by means of a unit $\frac{1}{12}$ of an inch in length, this unit being contained in the two indicated lengths 40 times and 25 times, respectively. If we should use a unit 5/12 of an inch in length, and hence five times as long as the preceding unit, then it would be contained eight times and five times respectively in the two given lengths.

Now Pythagoras conceived the ideal lines present in geometry as natural elements truly existent to the mind. His number speculations regarding the nature of things would therefore cause him to seek a common unit in terms of which to measure by means of numbers (positive integers) any two lengths which might be presented to thought. And any failure in such an attempt would be a serious blow to his number speculations. Just such a failure confronted him. He observed the existence of two lines not having a common unit of measurement: and this fact produced much consternation.

The discovery was made in this wise. Pythagoras, so it is said, had proved the general theorem that the square on the hypotenuse of a right triangle is equal to the sum of the squares on the two sides. Now consider a right triangle with two equal sides, and seek a common unit for measuring a side and the hypotenuse. Suppose that such a unit exists and is contained m times in the hypotenuse and n times in a side. m and n being positive integers. Then the square of m is twice the square of n. Hence the measure m of the hypotenuse is necessarily an even number. Now drop a perpendicular from the vertex of the right angle to the hypotenuse. This divides the original right triangle into two equal right triangles, each of which has a hypotenuse of length n and sides of (integral) length $\frac{1}{2}$ m. Since n measures the hypotenuse of one of the new triangles, it follows from the foregoing argument that n must itself be even. Since m and n are both even we may double the original unit of length and still measure the side and hypotenuse of the original triangle in positive integers. But from the former argument these latter integers are both even. Hence the unit of length may again be doubled without interfering with the required type of measurement: and this process of doubling the unit of length

may be repeated indefinitely without hindering the measurements. Since this conclusion is manifestly absurd it follows that the original hypothesis of a common measure for the side and the hypotenuse of an isosceles right triangle is incorrect. Therefore no such common measure exists.

This difficulty in the connection between integral numbers and things was clearly perceived by the Pythagoreans. Whether the foregoing proof of the existence of this difficulty is that employed by them I do not know, but it is certain that it runs entirely in terms of ideas to which they gave much attention. The result confronted them with a great challenge in their attempt to think clearly about the nature of measurement; and that challenge has been highly fruitful of ideas and theories both in mathematics and in all those parts of science which depend upon theoretical precision of measurement.

Here we find the beginning of that process by which mathematical analysis has, in modern times, been reduced to an arithmetical basis. Prior to this reduction the conception of the continuum of points on a line and of their mutual distances as the basis of measurement was intuitional in character. The same intuitive idea also underlay the concept of continuous motion. In order that a particle might move in a straight line from a point A to a point B it was said to be necessary that it should pass through every intermediate position in the line. But there was a failure to make a careful analysis of what is meant by *every* intermediate position. As long as one relies upon a vague intuition of this *everyness* there is lack of clarity in thought; essential difficulties are involved which can be removed (if at all) only by a thorough analysis of the whole situation.

You will not expect me to follow through in detail the arduous steps of progress from the Pythagorean discovery of the existence of incommensurable magnitudes, and hence of what we would now call irrational numbers, to the modern analysis of the continuum of points on a line. It took the human mind well over two thousand years to pass from the first step in this direction to the attainment of a fairly satisfactory foundation in relatively recent times. But this development has proved itself essential in making secure the foundations of mathematical analysis and in providing an adequate theory for scientific measurement.

Kepler was convinced that God created the world according to number, and this conviction inspired his arduous labors in seeking the real cause of planetary motions. He was not tediously searching for empirical rules: he looked for ultimate causes; he sought in number the secret of the Creator's mind. It is an irony of history that Newton replaced his mystical doctrine of numbers with a mechanical explanation in terms of the laws of force and motion.

The law of gravitation, as developed by Newton, is expressed by means of a very simple relation among numbers. Into this relation is incorporated a wide range of experience and observation; and from it prediction of further scientific results can be deduced. There is probably no other law or principle in science whose history bears so many indications of distinction. The work of Newton is marked by a clarity and penetration of thought and a lucidity of reasoning not previously experienced by man in thinking about the things around him. The numerical precision of results is so great that even very small discrepancies between theory and fact must be revealed if they exist and measurement becomes sufficiently refined to detect them. Thus from precision of thinking and clarity of result it became possible to compare Newton with Einstein

and finally to accept the latter as against the former. Without the clearness and exactness of result contributed to thinking by number such choice would be impossible. And after relativity has thrown so much of human thinking into flux and the stress of intellectual clash has finally subsided, we find emerging from the relativistic battleground at least one absolute of thought: there is nothing in the theory of relativity to alter the count of a finite collection of objects. The absoluteness of the positive integer is vindicated even in the theory of relativity.

Though irrational numbers are necessary for an adequate theory of measurement there are still wide domains of science in which the positive integer reigns supreme. It lies at the root of the atomic theory. It has attained a new dignity in modern quantum phenomena. If it should turn out that space and time, as well as matter and energy, are atomic in character, it might very well happen that a new foundation for science would be laid entirely in the theory of positive integers. This would certainly serve to redirect the labors of mathematicians in the theory of numbers; and in science it might carry us far back toward the original views of Pythagoras.

One of the most marked relations of number to clear thinking in biology is that involved in the Mendelian theory of heredity: and here it is essentially the positive integer which plays the leading rôle. This theory affords good evidence of the importance of number in stimulating clarity of thought and in leading the way to developments having wide contacts and yielding far-reaching results.

We may allow the statistical element in the results of Mendel to remind us of the very considerable range of phenomena which are accessible to clear and precise thought only through the use of statistical methods—and these depend intimately and essentially upon number. But we can not feel highly elated over our success when we remember that even the wide use of statistical methods has left us unable to attain clarity of thought about the weather, even though there is nothing else with which we have lived longer or more variously.

We have always realized our failure to understand the weather intimately. But we have sometimes carried out processes of thought, where it seemed for a time that clarity had been attained by aid of numerical exactness, and have afterwards had the experience of finding that what was accepted as valid and important has not continued to carry the confidence that it had once inspired. Not even the presence of number is sufficient to always save us from stupidities. In the older psycho-physics, for instance, there seems to have been a misleading precision in some of the exact formulas put down as the results of experiments.

It must also be remembered that there are important chapters of science which do not come readily under the domain of number. Witness much of biology and in particular the theories of phylogenetic development. As another example: It is difficult to see how the Gestalt psychology, with its emphasis on form and configuration, can be reduced fundamentally to terms esssentially involving only number. The task is even more forbidding in the case of psychoanalysis.

But enough has been given to show that precision of thinking may inhere in living thought and be supported by number; it is not solely the dead bones of truth that are subject to numerical precision. The changing contour of an organism of knowledge which pulses with life may be understood in the relations of its parts with a precision comparable to that which reigns among numbers; and exact numerical conditions

are often the means by which we understand the active life of living thought.

If I may be allowed to vary somewhat an English translation of a stanza of Schiller's, I may speak thus:

> No Augustan epoch flowered,
> No Maecenas favors showered
> Ever Number Science on;
>
> She was not by glory nourished
> And her blossom never flourished
> In the rays of Royal sun.

On the contrary the development of the science has grown out of the delight experienced by certain intelligent spirits in unfolding the relevant concepts and drawing appropriate consequences. And such delight is all the justification needed for any conquest over ignorance —the sort of conquest that never leaves any lingering regret—or any Polish Corridor. But the human mind is so constituted that when one thinks for sheer joy he is very likely to run into matters having philosophical implications. This and the fact that abstract number theory arose in a school of philosophy might lead us to expect that number has important contacts with general speculation. We shall now see that this is so and moreover that number has so tamed the beast of speculation as to bring some of his wild jungles under the plow of intellectual cultivation.

But before we take up that matter let us digress, by way of recreation, to hear a warning to any mathematician (if one exists) who is inclined to trust too much to his power and facility in handling numbers. This warning will be presented in the quaintly harmonious phrasing of an old English poem having peculiar and haunting rhythms. The verses run as follows:

> He that seeketh to *compute* his way to the wonders of mathematics
> And delighteth not in ideas
> Shall be grievously tormented:
> In anguish he shall die in the wild jungles of formulas,
> His heart shall be pierced by the poisonous symbols:
> But he that meditateth frequently in silence
> And seeth the truth oft without symbols
> And delighteth much in ideas comprehended
> Shall get marvelous strength from the dangerous symbols
> And tame the jungles of wild formulas;
> He shall roam at his will in their borders,
> Constraining their giants to his bidding,
> Unfolding the truth for the ages;
> And in joy he shall bring the gift of his thinking
> And bestow upon man a perpetual blessing,
> And for a while he shall be gratefully remembered:
> But he that seeketh to compute his way to the goods of the science
> And delighteth not in ideas
> Shall be grievously tormented:
> In anguish he shall die in the jungles of wild formulas,
> And oblivion shall cover him over with kindly forgetfulness.

If this recreation is insufficient and you do not yet feel like submitting your mind to the arduous task (now before us) of engaging in abstract considerations about infinity, I would suggest to you a little exercise in applied philosophy: while I talk about infinity, and some other things of like magnitude, you might amuse yourself by considering whether an after-dinner lecture is *really* infinite in length or only *seems* so.

As I proceed, you must understand that I mean to talk about what is really infinite and that I am not using the word loosely and irresponsibly, as Southey did when he said (in 1796) that "the number of fools is infinite."

The subject belongs to the domain of number as Locke had already divined in 1697 when he said: "Our idea of infinity . . . seems to be nothing but the infinity of number."

The unlimited straight line can not be measured off by the repeated application of any unit of length, however great; beyond any point on it which we can imagine, we can think of another

still further away, and of another beyond this; and so on. We may therefore say that the line is infinite in length. Any line segment, however short, may be separated into equal parts; and each of these parts may be separated into halves; and these latter may again be so divided; and so on without end. A line segment is infinitely divisible.

However far back into the past we extend our thought, we can conceive a time still earlier, and then another preceding this, and then a still earlier one, and so on *ad infinitum*. Beyond any future time conceived we can think of another still more remote. Time seems to be infinite in both directions.

There is a shorter distance than any we have measured and a longer than any we have conceived. No clock can fix an interval of time so short that we can not conceive a shorter. No geologist or astronomer has used so long a period that we can not think of a longer.

All these things bring the infinite to our thought; but the infinite as it emerges here appears always in a negative aspect. It is that which is not attained to by the finite. Such an infinite is that vague incoherent thing which remains over and beyond the reach of the finite. These conceptions present the infinite to us only as that which is not something else, that which is not the finite. But we can hardly come to understand the infinite merely by saying what it is not. If we are to be clear in our thinking about it we must say what it is.

The notion infinity appears in mathematics in two essentially different ways.

If a given magnitude x is variable and is subject to a law of variation such that x becomes and remains larger than any whatever preassigned magnitude that may be named, then x is said to become infinite. If a positive variable becomes and remains less than any assigned magnitude, however small, then we say that x is infinitesimal and approaches zero. These concepts of the infinite and the infinitesimal are closely akin to the infinitudes of measurement and of subdivision about which we have spoken already. While the concept of infinity is usually invoked here, as we have indicated, it is nevertheless not strictly applicable. If one carefully inspects the definitions given, it will be seen that they run entirely in terms of the finite and that no transcendental numerical idea is involved in the statements of them. Here we have not the genuine concept of the infinite but rather of certain types of variation.

The most remarkable, and at the same time the most characteristic, mathematical doctrine of the infinite is that which belongs to the theory of the so-called infinite aggregates or infinite classes. It is defined by means of numbers in accordance with the prophetic dictum of Locke already quoted. While it may be true, as Samuel Johnson said to Boswell on March 16, 1776, that all minds are equally capable of attaining the science of numbers, it is also true, as Johnson further said on the same occasion, that the type of one's education makes a great difference in the facility one has in penetrating to an understanding of number-theoretic considerations. I shall therefore have to ask your patient attention to some preparatory details if you are to understand the definition of infinite classes now about to be presented.

Suppose that you are in a Christian country and are attending a party where it is known (if I may speak formally, as the mathematicians do) that for every woman present there is a man present who is her husband and that for every man present there is a woman present who is his wife. Then you do not have to count those in attendance in order to know that the number of men present is the same as the number of women. Since by hypothesis this is taking place in a Christian country, the marital relation

establishes a one-to-one correspondence (unfortunately, we can only *hope* that it is a permanent one) between the men on the one hand and the women on the other of such sort as to imply equality in the numbers of the two sexes present. Moreover, you would also readily know something more about this group of men and women, as we shall now see.

Suppose for the moment that the men are all placed in line and that each woman takes a position just in front of her husband—it seems to be the present-day expectation for her to be thus a little ahead of him. This will exhibit to the eye the one-to-one correspondence already mentioned. Now suppose further that the men remain in position while the women assemble in a group and then separate again, each taking her position in front of a man but not necessarily in front of her husband, getting ready, let us say, to go out to dinner. This arrangement will set up a new one-to-one correspondence between the men and the women—let us hope that it will be a temporary one. It will be found, as you will readily agree, that the one-to-one correspondence is complete in the sense that there is no man not accompanied by a woman and no woman not accompanied by a man and that to each person of either sex there is assigned just one person of the opposite sex. A trivial observation, you may at first be inclined to say. Not at all. It is a fundamental fact: indeed it is perhaps the most important fact there is about two equal finite classes when considered from the point of view of finiteness and equality of numbers in the two classes.

This observation may indeed be used to define a finite class. A class A is said to be finite if there exists a class B whose elements can be put into one-to-one correspondence with the elements of A and if furthermore it is true that however the elements of A (without omission) are put into one-to-one correspondence with elements of B the process completely exhausts the elements of B.

If this definition is not clear, it may be well to go over it again, thinking of the class A as the men in our fictitious party and the class B as the women.

A corresponding definition of infinite classes may be given. A class C is said to be infinite if there exists a class D whose elements can be put into one-to-one correspondence with the elements of C, while at the same time it is true that the elements of C (without omission) may be put into one-to-one correspondence with a part of the elements of D, some of the elements of D (or at least one of them) being omitted in this correspondence.

If you have never before thought of these matters such a thing may well seem to you to be impossible. But, that there actually do exist infinite classes, in the sense of this definition, you may readily be convinced in the following way. Let us think of the totality of all positive integers 1, 2, 3, . . . , attaching to each of them the color blue (or writing it with a blue pencil) for the sake of identifying it as belonging to this particular class. We shall now prove that these blue integers form an infinite class, in the sense of the foregoing definition. To do this let us exhibit the class of red integers 1, 2, 3, . . . (written, let us say, with a red pencil). A one-to-one correspondence between these two classes may be set up by making the following correspondences: blue 1 to red 1, blue 2 to red 2, blue 3 to red 3, and so on. In this correspondence each class is uniquely exhausted. But note also that we can make the blue integers correspond completely, in a one-to-one way, to a part of the red integers, as follows: to blue 1 assign red 2; to blue 2 assign red 4; to blue 3 assign red 6; and so on; to each blue number assign the red number which is just twice as large. You will agree with me, I believe, that the blue integers are uniquely exhausted and are

in one-to-one correspondence with only a part of the red integers, indeed with just every other one of them and hence with just half of them.

The blue integers therefore form a class which is infinite in the sense of the foregoing definition. It is easy to prove similarly that the red integers also form an infinite class.

You will observe that the definition of infinite class which we are now employing is not a negative one. In this definition we do not define an infinite class by saying what it is not, but by saying what it is. This conception of infinity, when it first appeared, marked a great step forward in clear thinking. While it may be true that the inventor of this definition, as well as the mathematicians who have followed him, have been too profoundly convinced of its importance to present it in the colorful holiday garb which I have introduced here, it is nevertheless true that the playfulness has in no way obscured the fundamental idea underlying the definition. It is hoped that the Christian party and the colored numbers will afford an aid in remembering one of the most fundamental facts about infinite classes; indeed, just that one which separates them most sharply and most characteristically from finite classes.

In the case of the two infinite classes which we have had before us, namely, the blue integers and the red integers, it will be remembered that it was found possible to put the classes into one-to-one correspondence. The question naturally arises whether two infinite classes can always be put into one-to-one correspondence. The answer is that this can not always be done, that it is possible to exhibit pairs of infinite classes such that elements of the two classes in a pair can not be put into one-to-one correspondence. This justifies us in saying that infinite classes exist which are not of the same magnitude. If two finite classes can be put into one-to-one correspondence then the number of elements in one of the classes is equal to the number of elements in the other. We may say that the two classes have the same magnitude as to number. If two infinite classes can be put into one-to-one correspondence, we may likewise say that they have the same magnitude as to number. If two infinite classes can not be put into one-to-one correspondence, then we may (and we do) say that they have not the same magnitude as to number. In fact, it is customary to refine this conception of difference in magnitude of two infinite classes in such a way as to justify us in saying, under certain conditions which have to be specified with care, that one of two infinite classes may have a greater number or a smaller number of elements than the other. In this connection it is necessary to analyze the further question whether two infinite classes may exist which are not genuinely comparable as to number: but we shall not undertake to go into this question.

It is not my intention to weary you with the proof that two infinite classes may be of different magnitude as to number. It may be said, however, that the points on a line can not be put into one-to-one correspondence with the integers and that this class of points has a "greater" number of elements than the class of positive integers, in a genuine sense of the word greater. On the other hand, it is known that the number of points in space is "equal" to the number of points on a line or on a line segment of length one, however paradoxical this statement may seem. It is also true, though perhaps it is not so strange, that the number of all rational fractions is "equal" to the number of all positive integers.

If you have any inclination to feel that these statements are getting away from the province of clear thinking and are approaching the field of irresponsible

speculation, I would like to reassure you. The propositions which we have asserted will bear the closest scrutiny. They indicate merely some of the first stages by which mathematics has conquered from metaphysics a most productive region of the domain of infinity.

If you are one of those energetic individuals who like to jump from exact thinking into speculation, the definite conquests in the field of infinity will afford a convenient point of departure for such a leap. You might, for instance, inquire whether the infinite universe of nature (if indeed it is infinite) is of such an order of infinitude (with respect to the number of miles across it) as the class of all positive integers (with respect to the number of its elements) or of some other order, as, for example, that of the number of points on a straight line. If you wish, I say that you might engage in such speculation: but I shall not now attempt to pursue it with you.

The conquest of the infinite has illuminated a large section of mathematics. It has helped us in unexpected ways in making the logical foundations of our science more secure. It has led to a new understanding of the nature of functions and of the functional relation. It has given us a penetrating insight which has clarified the whole of mathematical analysis, just that part of mathematics which has been most useful to the natural sciences. The development of the theory of the infinite and the use elsewhere in mathematics of the notions to which it has given rise have been the sources of great intellectual and esthetic delight to some of the finest spirits of our race—and human experience never yields a better intellectual fruitage than such delight.

PUBLIC HEALTH PROGRESS IN CHINA

By Dr. EDWARD H. HUME

YALE-IN-CHINA

THE visitor to China who has not seen that country for ten years is probably more impressed by the development of a modern health consciousness there than by any other single factor. Modern buildings were under way, railroads and motor roads had started, education was a source of national pride even before that period; but up to 1925 there was no national sense of responsibility for the health of the people. In one or two centers there were government medical schools, the two most prominent being the Army Medical School and the Naval Medical School. There was, however, no national center dealing with problems of health and no provincial organization which could be held responsible for a provincial health program. As early as 1920 the Province of Canton had seen the need of a public health program and had established a health administration under Dr. S. M. Wu as commissioner of health. Special attention was paid to sanitation, disease prevention, public health education and vital statistics. The plans were full of promise but were not uniformly enforced. It was a beginning, however, and Canton has to-day taken its place as an active center of the public health movement. One can not date the beginning of public health activity in China with Canton and fail to record the remarkable work done by the Manchurian Plague Prevention Service under the direction of Dr. Wu Lien-teh. Trained in public health in England, it was the disastrous effect of the pneumonic plague in North Manchuria in 1910 and 1911, which invaded almost every large city in Manchuria as well as many cities in North China, that led to the calling of an International Plague Conference in Mukden and the subsequent establishment of the Manchurian Plague Prevention Service. The work achieved over a period of twenty years by this organization in the domain of plague prevention and bacteriological research is a matter of international record. Due to the leadership of Dr. Wu, the Chinese Maritime Customs began the practice of appointing health officers at the important ports throughout China. Suitable quarantine regulations were also drawn up and enforced, being eventually taken over from the Maritime Customs Service by the National Quarantine Service in 1930. A later outbreak of plague in the Province of Shansi in 1917–18 led to the establishment of the Central Epidemic Prevention Bureau in Peiping. From this center there has gone out a steadily increasing output of standard biological products which have been in great demand throughout China and have been of inestimable service in dealing with infectious diseases.

By September, 1925, a Health Demonstration Station was established in Peiping with the object of promoting public health work in the old capital and of providing facilities for instruction in public health to the students of the Peiping Union Medical College. The station provided for four branches of work—general sanitation, vital statistics, medical services and control of communicable diseases. By 1928 a health department was created in the Peiping municipality and placed under the direction of Dr. T. F. Huang. This department was conspicuous because it insisted on the registration of medical practitioners and because it was the first body to establish formal training in midwifery. Dr. Marion Yang, who had made a special study of midwifery in Europe and America, was appointed

director of the First National Midwifery School, which was opened in Peiping on November 1, 1929. Clinical material was made available in an adjoining maternity home.

After the establishment of the National Government at the new capital in Nanking in 1927, a Ministry of Health was created in 1928. Two years later its name was changed to the National Health Administration, which has continued to function under the Ministry of the Interior, with Dr. J. Heng Liu as its director. On July 1, 1935, the National Health Administration was made a direct responsibility of the Executive Yuan, thus placing Dr. Liu in immediate relationship with Mr. Wang Ching-wei, the president of that Yuan. In other words, the health responsibility of China, which was only a hope in scattered provinces a few years ago, has now been vigorously assumed by the executive branch of the government and made a matter of great national concern.

In August, 1929, the area known as Greater Shanghai was provided with a department of health. Here in the short space of three years, Dr. H. K. Hu organized a new service and divided the activities of the health department into four groups—vital statistics, health education, meat and dairy inspection and communicable disease control. After the untimely death of Dr. Hu in 1932, Dr. T. A. Li was appointed to the post of commissioner of health, and because of the sympathetic support of the mayor of Greater Shanghai has been able to amplify the work of the department and to extend it in many directions. Conspicuous at the health center is the large municipal hospital with 500 beds whose buildings will shortly be opened to the public. Provision has been made for an infectious disease hospital nearby, and an active laboratory service is already under way in the central office building of the department. Greater Shanghai is subdivided into thirteen districts, in each of which a special health station is to be created. So far, four health centers have been organized, and the work in these units is a conspicuous illustration of a modern public health program. The four districts are Kaochiao, Woosung, Kiangwan and Nantao. The commissioner of health has announced the aim of the Bureau of Public Health to be "to make the residents of Shanghai healthier, happier, more efficient, and to enable them to live a greater span of life."

In 1929 a public health department was also established in the capital city of Nanking. It is a municipal organ but is subject to the supervision of the National Health Administration. The capital is fortunate that the Health Administration includes such a group of units as the Central Field Health Station, the Central Hygienic Laboratory, the Central School of Midwifery, the Central Hospital and the Central School of Nursing. These make possible both a national and a local emphasis on health activities never appreciated before.

To quote a recent sketch by Dr. J. W. H. Chun in *The China Critic* (June 6, 1935): "It will at once be apparent that the outlook of public health work has taken on a national character. With the motive power central in the capital city, we find the provinces and large cities are undertaking new activities in public health and medical work. Newly established health departments are springing up in one provincial capital after another, and technical institutions are constantly being added so that we now have a fair number of hygienic laboratories, midwifery schools, public clinics, and municipal hospitals." Moreover, the registration of over 6,000 physicians practicing modern medicine is well under way, while the 250 missionary hospitals and several hundred other hospitals are to be counted on as a part of the total medical program.

The National Health Administration is now establishing a new outreach into the provinces. Health commissioners have already been appointed in Hunan.

in Kiangsi, in Chekiang, along the Yangtze River. Similar appointments will presently be made for the provinces of Hupei, Anhwei, Szechuan and Fukien. The Central Government has also appointed health commissioners to the northwestern group of provinces—Shensi, Kansu, Chinghai and Ninghsia. The extension of public health activities in the northwestern area has been greatly facilitated by the experienced commissioners lent to China by the League of Nations. Dr. Borcic served from 1931 to 1934 and has now been succeeded by Dr. A. Stampar, that distinguished Yugoslavian public health worker so vividly described in "The Native's Return," by Louis Adamic, under the title, "Doctor Hercules." It will be recalled that Adamic speaks of Dr. Stampar in these words: "Of the prominent men I really liked and admired only one—Dr. Andriya Stampar, a public-health expert who, in the last decade, developed in Yugoslavia a system for looking after the people's health which, to my mind, is one of the most dramatic and noteworthy achievements in Europe since the war."

In May, 1935, Dr. Stampar reported to the National Health Administration on the development of health institutions in the northwest provinces, laying great stress on the recent growth of communications in that area. The Lunghai railway now reaches from the east coast of China to the capital of Shensi Province, a distance of 1,200 miles. Motor busses run from this capital to the capital of Kansu, a trip still requiring four days. Air services, however, have been established and make communication prompt and effective. The railway line running from Peiping out along the northern aspect of the Great Wall make it possible to maintain excellent communication between the eastern provinces and that northwestern area which was until recently regarded as a sort of *ultima thule*. Some of the noteworthy elements in progress discovered in the northwestern provinces by Dr. Stampar are:

(1) The suppression of opium, which is presently to be replaced by cotton growing.

(2) The cooperation of government agencies with private banks, making financial resource accessible to the farming population.

(3) The tremendous increase in the area of irrigated land.

(4) The establishment of rural cooperative societies, there being over 1,000 in the Province of Shensi alone.

(5) The widening of streets, the provision of electric lighting plants and the water supply in the capital city of Siam at the center of Shensi Province.

Dr. Stampar sums up his report by saying, "In my opinion, the most important progress was made in the awakening of a real interest on the part of the local governments and local population in reconstructive activities."

The striking developments in the northwest during the past year may be summed up as follows:

(1) In the first place, there has been set up a Northwestern Epidemic Prevention Bureau. The Central and Provincial Governments cooperated to provide the necessary financing, both in the way of capital expense and in the way of running expense. In the bureau a large number of laboratory specimens have been examined, pupils in schools were given vaccination against diphtheria and smallpox, general dispensary activities were set under way, and a large veterinary clinic (for horses, mules and donkeys) was opened. It will be remembered that in this area there is a considerable amount of anthrax, mallus and rinderpest. Many epidemics have occurred during the last three years, and in certain counties thousands of animals have perished. Two counties report a mortality of 90 per cent. of their animals from rinderpest. In other counties there were thousands of deaths among animals from sheep pox, from foot and mouth disease, from glanders and from anthrax. The capital of Kansu Province has now

set up active supervision of slaughter houses and dairies, with special attention paid to the animals to be used under the military authorities. The manufacture of anthrax vaccine and mallein was started, and large numbers of horses were vaccinated at the request of the military authorities.

(2) Provincial health centers have been set up in Shensi, in Kansu and in other adjoining provinces. In Shensi the two chief units were a school health center and a midwifery school. The former "paid special attention to health education by means of meetings, health education courses and health exhibits. The meetings were attended by about 4,000 persons. Thirty-two teachers took the course in training for teachers. Forty-two were enrolled in other courses. The school health centers are well supplied with posters, books, models and publications for health exhibitions. From the beginning of activities of the school health center, 6,639 students were examined, and of these 5,937 students were found with remediable defects."

Special attention was given to the students in such institutions as the School of Hydraulic Engineering and the Northwest Highway Administration. Here the most prevalent disease among students was found to be trachoma, for which nearly 30,000 treatments were given during the eight months ending in May, 1935.

The second unit is the midwifery school, erected on land given by the Provincial Government with the aid of a special donation from a Chinese philanthropist in Singapore and a special grant from the British Boxer Indemnity Fund. The school has a maternity home with forty beds attached to it and is responsible for maternity and child welfare work. In the first nine months, over 600 cases were attended in this home.

In the neighboring province of Kansu, the health center included a public dispensary, school health work throughout the eight high schools of the capital city, with regular physical examination and school health training courses especially for primary school teachers. One unique experiment here is the control of midwives of the older type. In the vicinity of Lanchow the City Police Department compelled the enrolment of 37 midwives of the old wives for several months of cleanliness and prenatal hygiene. The police force itself was required to attend courses in public health education, and a number of public health nurses were employed to explain health matters to patients waiting in the dispensary. In addition to this, special health plays were given which attracted several thousand people and provided a thoroughly Chinese method of extending health knowledge.

Dr. Stampar reports how deeply he is impressed with the fine spirit and enthusiasm which have prevailed among the staffs of the provincial health centers in the northwest. Fortunately, as he points out, there has been, concurrently, a general improvement in agricultural methods in the establishment of schools and communications and in the rigorous campaigns for the suppression of opium.

Before long, similar reports on public health progress will be available from other areas in China. The Province of Kwangsi has become energetic in extending communications and education. We shall presently hear great things about its activities in public health. So, also, as the communist armies have been driven out of the Provinces of Yunan, Kweichow, and out of large portions of the Province of Szechuan, reconstructive work, particularly in public health, will take the place of the dissipation of provincial resources that has been prevalent in these three areas. Public health has become a reality in China and its opportunity is boundless.

IN QUEST OF GORILLAS

II. TANGANYIKA SNAPSHOTS

By Dr. WILLIAM KING GREGORY

CURATOR OF COMPARATIVE ANATOMY AND OF ICHTHYOLOGY, AMERICAN MUSEUM OF NATURAL HISTORY; PROFESSOR OF PALEONTOLOGY, COLUMBIA UNIVERSITY

A DAY ashore at Mombasa was crowded with colorful sights. The land itself is bright red or yellow in color; upon this is the rich green of the tropical trees, including breadfruit, papaya and cocoanut palms. Black folk swarm everywhere, some with evident traces of the blood of the old slave-raiding Arabs, whose fortress and trading-station Mombasa was. Each black face shines with an irresistible quality of quaintness or comicality, if you will, of which I never tired. Many are bovine and placid, with massive noses and mouths; occasionally the old men look crabbed and cynical; the little boys' eyes sparkle with fun and the tiny children either run away from you and squeal or come out with a snappy salute. The women vary from lithe straight amazons to weary and flaccid drudges. Noses usually are of a generous breadth and flatness but sometimes are narrower, recalling Hamites and Arabs. Thick lips usually bear a pronounced and regular "Cupid's bow." Hair is frankly woolly, innocent of the anti-kink decoctions favored by American Negroes.

In Mombasa, as in other East African places, the old Portuguese and Arab influences are now more or less overlaid by the flood of Indians, both Hindus and Moslems. The English seem to hold only the few higher offices in the banks and government bureaus, while the Indians fill most of the clerical jobs and intermediate positions between the English at the top and the blacks at the base.

Thus the old and the new are jumbled together. Ox-carts are crowded by American, French and English cars, which swarm everywhere, some of them driven by black boys with their front teeth filed into sharp points. When we asked our chauffeur for the afternoon why his teeth were filed, he said in effect that it was to make them look decent and presentable and to keep them well and fit; but the whites say that a short time ago these teeth-filing people were cannibals. Later we heard a still more dramatic explanation. When a man is sick unto death, his jaws shut tight and no one can give him water or medicine to help him in his dark hour, unless he has plenty of spaces between his front teeth.

Out in the villages where we drove that afternoon we could see frequent evidences of the dark hours of life, scattered among those spent in basking in the sun or whirling in the dance. For grievous sores afflict the people, and relatively few can or will stay long enough at or near the hospitals to get cured. Also, through some faulty technique of their midwives, umbilical hernia is widespread; most children have immensely distended abdomens, possibly from worms or malaria. Infant mortality is very high, from syphilis, yaws, blood-poisoning and many other causes.

In Mombasa and its environs we saw a few asses and donkeys that plainly spoke of North African, Portuguese or Arab influences; but on the whole, these animals as well as horses are very rare in equatorial Africa, obviously on account of the tsetse-fly and the sleeping sickness. The age of the automobile has in fact succeeded immediately upon the age of the tippoy (or sedan), while the age of the horse, when this poor beast

played so great a part in all the actions of peace and war, is conspicuously absent in equatorial Africa.

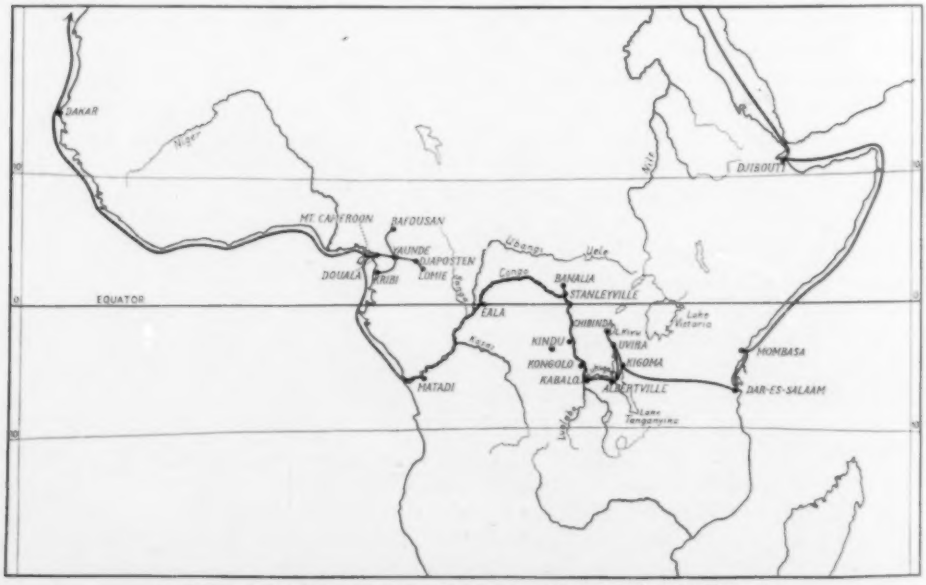
Another relic of North African, Egyptian or Arab influence we saw that day was a dromedary walking around a circular track and thus turning a millstone. During our ride in the environs of Mombasa we passed villages of thatched mud-huts, droves of goats and sheep and hundreds of Africans trudging along with loads on their heads or sitting at ease in front of their huts.

Then we drove back to the city past large walled gardens, along roads bordered with cocoanut palms. After returning to the hotel we strolled about town. In the park was a gigantic and distorted baobab tree, which was brilliant with red flowers; here also was a grove of squeaking bamboos and other strange trees. After dinner at the hotel we went back to our ship for the night.

After this foretaste of Africa we were glad enough when, two days later, our ship put in to the harbor of Dar-es-Salaam and we went ashore with all our impedimenta to the customs house.

We went to the New Africa Hotel—a relic of German East Africa (now Tanganyika Territory). This is a spacious and more or less Arabized white building with large arched porches, very high-ceilinged rooms, a central court and swarming black boys in white bag-like garments. A small tame reed-buck browsed in the inner court. Here we were obliged to stay from July tenth to July thirteenth, waiting for the bi-weekly train for Lake Tanganyika. We had arrived in the "winter" season, and the heat was by no means oppressive. In fact, the tropical African sun always surprised us by its moderation, although doubtless if we had been soldiers burdened with heavy marching equipment, we should have been less pleased with the weather.

At Dar-es-Salaam there was a great deal of tedious business to go through, especially the customs, the burden of which fell chiefly upon our leader, Mr. Raven; but I was free to come and go at will. My first walk was along the beautiful white beach of the outer harbor, which opened into the Indian Ocean.



ROUTE OF OUR EXPEDITION IN QUEST OF GORILLAS.

Photograph by H. C. Raven.

CHILDREN OF INDIA AT MOMBASA.

The sun at midday was undeniably hot, but no worse than it often is in New York, and my first lone ramble in Africa was richly rewarded by various small but interesting bits. After picking up many kinds of beautiful seashells I saw small lizards chasing each other over the blackened shell-rocks. The lizards were black, dappled with gray spots, and were exceedingly difficult to see when they sat still on the rocks. They reminded me of the dead-black lizards on the black volcanic rocks of the Galapagos Islands, of black crabs on black rocks, of gray crabs on gray rocks and many similar cases of protective coloration which have come under my personal observation. At that very moment a ghostly beach-crab revealed his position by moving. I gave him a lively chase. While he was running he was easily visible, but at the moment he stopped he instantly disappeared from view, his colors blending perfectly with that of the sand. In view of many such facts it is small wonder that field zoologists believe implicitly that concealing coloration is of great value to its possessor and that it is a result of natural selection, which in the long run enforces closer and closer approximation in color to that of the environment. In spite of the fact that natural selection has to wait for small mutations to appear before selecting those which chance to lie nearest to the optimum coloration for that race in that environment, geologic time is almost infinitely long and the numbers of varying individuals that appear are so enormous that nature has had time to add to the results already achieved new successive advances toward the optimum set by the environment.

In a few minutes walk I came to a rocky place of numerous tide-pools. Here little dappled fishes, which seemed to be gobies, skippered about furtively on the greenish-gray bottom. If I stood very quietly they would slither around cautiously, but if I let the shadow or image of

Photograph by J. H. McGregor.

GIANT BAOBAB TREE AT DAR-ES-SALAAM

myself or of my hand fall on the water they sprang out of sight instantly. Much larger little fishes with vertical flank stripes were doubtless young percoids of some sort. These darted about like flies when I pretended to try to grab them. The extreme agility of tide-pool fishes has long impressed me as a fine example of keenness of sensation and perfection of locomotor control.

Above me the bird world swarmed in the clear sky. There were soaring kites and darting swifts, while a kingfisher was performing the difficult feat of hovering, before shooting down after a fish. A few dignified cranes stalked in the distance. On the walk home busy little finches, jerky wagtails and aggressive weaver-birds chattered and flitted about. The ubiquitous Africans working on the road were glad to stop and turn their broad muzzles toward the stranger. Coming to a stone balustrade near the hospital grounds, I began a lively game of hide and seek with a large lizard of the skink family. No matter how cautiously I would poke my head over the balustrade he would jerk back through the open spaces to the opposite side. He was far more determined not to be caught than I was to catch him and I left him, marvelling at his competence in looking after his own safety.

One afternoon we hired an auto and drove out in the country to a fishing-village on the coast. The fish had been brought in and disposed of, but we were much interested in finding that the people used outriggers on their canoes, which reminded us of those used by the Polynesians. It would seem less fanciful to assume that the outrigger had been invented twice rather than that the custom had spread from Polynesia to east Africa. One little girl was terribly frightened by our pointing our cameras at her, but her father reassured her with the gentleness that seemed everywhere characteristic of the Africans in dealing with their children. Some of the fishermen had beautiful large seashells, which they set down on mats before us after the manner of Hindu merchants. But our baggage was already far too abundant for our long journey across the continent and our leader disapproved of all unnecessary additions.

Next morning before breakfast we went in rickshaws to the large fish-market of the native village of Dar-es-Salaam, but nearly all the fish had been disposed of before we got there. It was a pleasure, however, to recognize many fishes of the Indian Ocean that I had hitherto known only from pictures in Day's "Fishes of India." The memory of one olive-colored fish seen on this occasion has haunted me ever since, because when I saw it I could not identify even the general group to which it belonged. Soon afterward I made a rough sketch of it from memory and am now inclined to think it was a certain member of the surgeon-fish group, which I had always wanted to see because of its evolutionary interest, as it tends to connect the surgeon-fishes with more normal bass-like types. But my observations were made so hurriedly, standing in the market in the hubbub, that I did not think to look for a concealed "knife" on the side of the tail. Hence the chief diagnostic character of the group of surgeon-fishes may or may not have been present in this specimen. But although meriting reproaches for carelessness and haste, I record the incident as typical of the joyful puzzles that Africa continued to confer upon me all along the road from the east to the west coast. Thus if I had known much more about many subjects the elements of wonder, surprise and puzzlement would often have been absent, while if I had known much less I shouldn't have been interested at all. So perhaps I was fortunate in a way not to know any more than I did, but now, after having read a great deal on Africa, its geology, anthropology and zoology, it seems that I couldn't decently have known less.

At last we were seated in the train

leaving Dar-es-Salaam for Lake Tanganyika, with all our luggage stowed in the freight car. Thus we began a journey of 780 miles westward across the territory of Tanganyika. At first we traveled up the coastal plain, a moderately fertile land with plantations of cocoanut palms; then we began to wind our way up the rocky escarpment to the high central plateau which forms the greater part of Africa.

The railroad forms a wide desolate strip. The locomotives consume a prodigious amount of wood, and the cutting and burning has devastated the country far on each side. Game used to be abundant, but now it was only by constant watching through the long hours that we were able to see a few duikers, a wart hog and its young and several small groups of impalla antelopes, some of which leaped high in the air.

The people whose villages lie along the railroad cut the trees for the locomotives and abandon the villages when the trees are all cut down. They live in round straw huts and keep a few zebu cattle, goats and sheep. They are thus the fringes of what Sir Harry Johnston calls the "cattle-keeping aristocracy," who are straight-featured, handsome negroids, derived mostly from the southern Abyssinians mixed with the forest Negroes. The women, as usual, till the fields and fetch the water. Little boys drive the cattle home from the stubbly pastures. On this plateau the flat-topped acacia trees dominate almost as much as the eucalypts do in Australia.

Then we began to move down into the vast but shallow depression which is known as the eastern rift valley. This is, of course, part of an enormously long system of troughs, lake-beds and bordering mountains that straggles all the way from south of the Zambesi up through the African great lakes to Palestine.[1] From the hazy silent plain rounded hills or kopjes slowly appeared to rear themselves in the distance.

Soon we were in the midst of a world of shattered rock, the battle-ground of titans; in such a place Prometheus chained might have defied the utmost wrath of Jove, or Satan's troops have fought against the angels of light. Here were no puny human bulwarks but battlements of granite mountains strewn with mighty boulders; and great was the confusion and the desolation thereof. Low hung the billowy clouds above, in legions numberless to man; and beyond all the illimitable blue. Straining over the iron gate at the end of the train, I lift up mine eyes unto the hills and my spirit is filled with awe and exultation.

Up the other side of the rift valley the train wound its slow way, spiralling up through rocky passes to a still higher plateau, where we could look back at right angles to the very long straight track where we had crossed the plain. For a night and a day we traveled over this plateau region of incalculable antiquity. According to the geologists, this plateau has never been covered with the thick mantle of marine rocks such as are found in Europe and Asia. Also it has been fractured and broken into huge block-like areas which have suffered warping and vertical displacement.[2]

We continued on and up and over the mountainous plateau on the other side of the eastern rift valley until at last we reached the headwaters of a river that flows downward toward Lake Tanganyika. Following down this valley, which grew more and more fertile and green, we descended toward the lake. At last, after two nights and one day on the crowded train, we passed through a break in the rim of the hills on the east side of the lake and suddenly came out at Kigoma on the east shore of Tanganyika, one of the most beautiful of the African "great lakes." But about this more later.

We stopped beside a huge recently cut embankment, vividly red and flanking a spacious, smooth red plaza with broad,

[1] J. W. Gregory, "The Great Rift Valley."

[2] Bailey Willis, "Living Africa," 1930.

Photograph by H. C. Raven.

CONGLOMERATE AT KIGOMA AT ENTRANCE TO BAT CAVE.

freshly whitewashed trimmings. What a hubbub! A swarm of comical blacks rushed into the car, jabbering and struggling to seize and carry off our baggage on their thick-topped heads. Imitating the usual manner of the white man in Africa, I yelled at them, pushing all of them back, and made one of them pass one piece of hand baggage after another through the window to those waiting outside, where Raven and the others lined them up. In a few moments we started off in a procession to the imposing white railroad station that rears itself high athwart the end of the railroad. All our personal baggage was accounted for, but the baggage-car containing our extensive equipment would not arrive until later, perhaps the next day, perhaps after our boat had left Kigoma!

Then we went up the long red hill to the "Greek hotel," which, fortunately enough, was already jammed with travelers. Fortunately also the *Baron d'Hanis*, the big lake steamboat, was tied up at the wharf for repairs and the captain very kindly gave us permission to come on board as passengers and occupy cabins for the next night or two until a smaller steamer should be ready to start on its trip up the lake. The head steward kept the galley going even when the vessel was hauled up on the dry dock.

For a while we stood outside the hotel and watched men, women and children coming up the hill, many carrying loads on their heads and walking as straight as arrows. Even a bottle or a can of tomatoes would be poised as steadily as a load of fifty pounds.

Here comes along the red hill road a gang of dusky savages with goatskins draped over their shoulders. They are carrying a heavy load of corrugated iron

Photograph by J. H. McGregor.

BOAT WITH OUTRIGGERS, DAR-ES-SALAAM.

sheets, which are used to roof most of the white men's buildings in equatorial Africa. Strange to say, their tongues are silent for a second or two, only the soft tread of their feet being audible. Suddenly, as the load sways back and forth on their patient heads, some one gives out a quick but mournful theme—then the chorus breaks in, rippling and swishing back and forth in unpredictable antiphony. I listen entranced. What words could be adequate to such inspired music? Is the song itself as sad as "Old Black Joe" or as stirring as "Old Man River"? Alas, no! The words are probably trivial and with little dramatic value; at least, so I was told by a student of African music.

One moonlight evening I stood still and listened intently to the men who were loading logs of firewood into the boiler-room of the lake steamer. The black

Photograph by H. C. Raven.

THE TYRANT OF AFRICAN WATERS (HYDROCYON CF. LINEATUS.)

chorister on the wharf grumbled a bit as he lifted a heavy log: "*Heave ho-a*" would be the meaning perhaps of the magic words that he sang; down thumped the log on the steel floor of the pit.

"*Garrump-a lunk-a,*" or words to that effect, responded Shiny-eyes below, who kicked the rolling log along.

"*Whumph-ala bam,*" moaned White-teeth, as he chucked it on the pile. So was their labor lightened and their humble hearts gladdened by the divine Muse.

While they were singing I could imitate them, at least to a certain degree, but afterward their refrain soon joined the long sequence of "Lost Chords" which now haunt my reveries of Africa. What an opportunity there is for some future Dvorak to compose an African symphony, weaving the songs of men that carry burdens and of women that dance to the rumble and thumping of big and little drums.

While we were waiting for our tardy baggage-car, as well as when we returned to Kigoma several months later, I took several walks around the bay, rejoicing in the opportunity of walking on the shores of Lake Tanganyika, which teems with interest to the naturalist. At the radio station there is a promontory composed of massive gray metamorphic rocks, part of the excessively ancient African continent. The shore is covered with large angular fragments which are so dense that they have withstood the action of the usually quiet waters; the shore in this place is literally without sand.

Here I found the following fragments among the scant flotsam and jetsam: first, half of the lower jaw of a hyena, which was easily identifiable by its massive curved lower border and huge cutting cheek teeth; next, there was a bony plate, evidently from the nape of the neck of a large catfish; next, an old nest of some fish-eating bird, containing fragments of fish skeletons too small for identification. The visible life on the rocky shore at this point was extremely scant: no flies, no crabs, very few mollusks. In the pools of water in the foreground I found a small olive-colored water-snake, which insisted in crawling out of an old tin can in which I placed him, even after his spinal cord had been severed just behind the brain. Apparently the reflex systems in his spinal cord were sufficient to keep him trying to climb out of

Photograph by J. H. McGregor.

THE MANGO TREE AT UJIJI

WHERE STANLEY MET LIVINGSTONE IN 1871. THE MONUMENT COMMEMORATES THIS EVENT.

that confined space. I treated him a bit gingerly, as the chances that he was poisonous were fairly good. Recently I learned that this little snake represents a rare water-living species of cobra, which hides under the rocks on the shore of this lake.

The large pools and open water near shore were inhabited mostly by a single species of very abundant, small bass-like fishes, swimming in schools, which I watched for a long time. The water was so clear and rippling in the early morning sunshine that I took off my clothes

Photograph by E. T. Engle.

DR. RAVEN AT UJIJI. HE IS ABOUT TO TOSS A SMALL COIN TO THE BOYS

and went in for a swim, being careful, however, to remain quite near the clear water by the rocks. Afterward my enthusiasm for bathing in the lake was somewhat dampened by finding the scattered bones of a large crocodile right near this spot.

On the shore of the lake I found a large cycloid fish scale, which I afterward learned was probably possessed by one of the big characin fishes, such as *Hydrocyon* (p. 512). But all fish equipment was still packed and in bond.

After my swim I went southward along a beach where the waves had ground the rocks up into very coarse sand. On the way I passed across fields where there were enormous grasshoppers in green, red and yellow. Here also dense ledges of nearly horizontal, dark purplish-red sandstone concealed the old crystalline rocks, which doubtless lay beneath them. This was the first time I had seen any rocks of this wide-spread system (Lualaba-Lubilash), which corresponds in a general way to the Karroo system of South Africa.[3]

Going on a short distance to the south shore of the bay, I came to a huge promontory called the "Elephant's Foot," which juts out into the lake. This is formed of a conglomerate containing untold thousands of oval pebbles, many about as big as eggs. This conglomerate seems to overlie the formation of horizontal sandstone exposed near by. The pebbles in it have been rounded by ancient streams and then imprisoned in the mud, and the whole has hardened into rock. Some of them were now weathering out of the rock and being set free again on the shore of the lake. Probably this conglomerate is of recent age, as the pebbles are not solidly fused in it. The whole surface of the rock toward the lake is beautifully rounded, probably through the combined action of rain and waves.

[3] A. C. Veatch, "Evolution of the Congo Basin," *Geol. Soc. Amer.*, Mem. 3, 1935.

The promontory is cleft by deep incisions, one of which extends far inward as a sort of cave. I crept quietly into this dark passageway and was delighted to find it thickly populated by large bats, which flitted over my head to the darkest niches behind and above me. One or two bats still clung to the wall that was partly illuminated by the light from the passageway and as soon as my eyes became accustomed to the semi-darkness I could see clearly that they had enormous ears and pointed muzzles. Later when we all visited this spot together we secured several of the bats in a net and Dr. McGregor got a cinema picture of one of them.

While we were at Kigoma, three of our party went over to Ujiji, a village near by, which is famous as the place where Stanley met Livingstone in 1871. Here the native population showed considerable Arab intermixture, as this was one of the great Arab headquarters for the slave trade.

After a two-day wait at Kigoma, our baggage-car came in and both the English and Belgian customs officials were exceedingly helpful in speeding it through the custom houses. In the evening we went on board the *Urundi*, a small lake steamer, and thus entered officially into the vast empire of the Belgian Congo. The boat was crowded with passengers and there were no staterooms available, so we spread out our bed-rolls on the foredeck just behind the anchor chains and winch. It was a moonless starry night, and after a somewhat too obliging passenger with an enormous accordion had exhausted his repertory—to say nothing of us—we lay down and slept till dawn.

Numerous bush-fires dotted the low mountains along the lake with dark glowing spots. These bush-fires, as we learned, occur almost everywhere in the highlands of Africa during the dry season and have inflicted incalculable damage to the forest and native fauna. As they have probably been going on for hundreds of years, they have left thousands of mountain-sides bare, except for the coarse grass and thick underbrush that spring up quickly in their wake. The fires are mostly set by the natives, both after the forests are cut away for their timber and when new crops of underbrush cover the pastures.

All that night and the next day we sailed north along this great and exceedingly deep Lake Tanganyika, the surface of which is about 2,680 feet above sea-level. The fiord-like valley which it fills is part of the Western or Albertine rift system, which, as already stated, extends southward into Rhodesia and northward through Lake Albert to the chain of lakes that passes northeastward through Abyssinia to the Red Sea. In the waters of Tanganyika, as we later found, live many organisms of apparently marine affinities: a fresh-water medusa (which we saw floating in schools near Baraca), oysters, allied to marine types, small crabs of an essentially marine family, cichlid fishes belonging to a family which is rather closely related to the marine percoid fishes, and many other organisms.

How did these once marine creatures get into this now land-locked lake, so high on the tableland of central Africa and so far from the nearest sea-coast? The answer, according to most zoologists and geologists, is that parts of the great rift system of fiord-like depressions were originally connected with the Indian Ocean, either in the northeast, as the Red Sea now is, or at the southern end along the continuation of the rift system below the recent Zambesi River. Relatively recent earth movements and volcanic outpourings have perhaps pinched off the ends of the system in Africa and left a chain of separate lakes; in these the water has gradually become fresh without destroying all the marine creatures that had flowed in from the ocean when the great rift was established. It

should be noted, however, that Professor MacFarlane, of the University of Pennsylvania, in his book on the "Evolution and Distribution of Fishes,"[4] states that none of the organisms mentioned above has been derived from marine forms, but rather that the reverse has happened, namely, that the really primitive organisms are to be found among the freshwater fauna. So far, however, as his argument rests on the evidence derived from the fishes, I find myself in detailed disagreement with his interpretation of the facts.

About noon of the next day our boat anchored off Usumbura at the northern end of Lake Tanganyika and began to transfer some of its black passengers to a smaller steamboat, which took them to the wharf, and at the same time to take on other passengers, both black and white. A fairly stiff breeze was blowing up the lake, and the little boat bobbed up and down more quickly than ours did. This lack of synchronism produced effects upon the poor debarking natives which were both amusing and thrilling to us, but about which they were not at all enthusiastic. Imagine having to pass nearly all your household effects by hand from the big boat to the little boat, or *vice versa*, in that bobbing sea! But how bravely the women stuck to their job of handing the babies and gourds and matting-rolls up or down to the men, who grabbed them and pulled them whichever way they were going. The babel of it was indescribable. One poor man got imprisoned behind a heavy rope that tied the smaller boat to ours; as the boat swung around it pressed him into a pile of baggage and threatened to cut him in two at the waist. Anybody but a native would have been at least breathless, but after emitting sundry emphatic remarks, or volumes of remarks, he shook himself like an indignant rooster and climbed off the boat. Meanwhile the mate was cuffing the dumbhead that was responsible for the mishap. From the swaying upper deck I was rejoicing in a nearly top view of some of the widest, most imposing noses I had ever seen, some of which even a "missing link" might not disdain to own. These people were soldier-police and their families, detailed to stop a while at this town and make the prisoners work on the roads. If they had been Sicilians, somebody would probably have been knifed as an expression of resentment; but being Africans, after the uproar they counted it all as part of the day's work and forgot it.

From Usumbura our boat turned to make an arc across the lake to Uvira, crossing the rapidly increasing waves. Every day when the clouds do not cover the higher mountains toward the northern end of the lake, the mountains become heated and a strong current of air rises from them, sucking the cold air above the lake toward them and stirring up quite a choppy sea. During this particular passage of the boat the waves were far too big for the comfort of the crowded passengers and the next hour was a time of gloom and misery of which the less said, the better.

Eventually, however, we passed into the quieter water in the lee of the mountains and soon we tied up at a wharf at the foot of a steep mountain of yellowish-gray crystalline Pre-Cambrian rocks. To come into view of a geologic formation that is new to me is always exciting and I was impatient to climb up the nearest of these jagged peaks and get a view of the lake and surrounding country. But it was then near evening and I had to restrain myself.

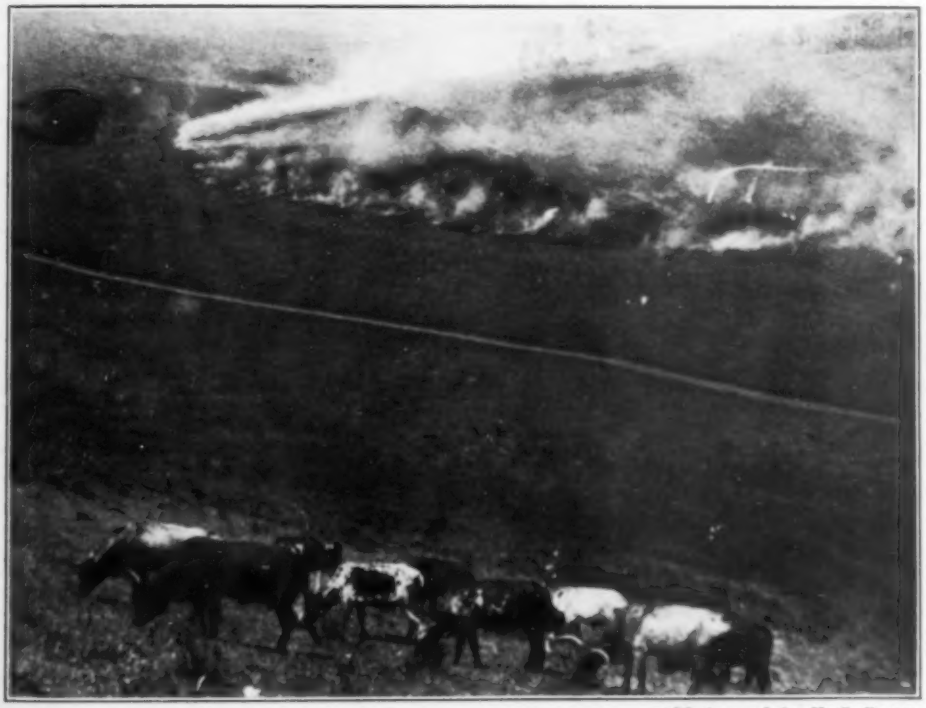
After a very long wait for our baggage and for a camion, we were whirled off in the night to one of the world's worst hotels. The one room available was fairly large and had four good-enough beds in it, but it opened on the barroom, where the American phonograph tried to outscream the full-voiced revellers, who were always celebrating some holiday.

[4] Macmillan Company, 1923.

The management paid us the compliment of feeding us as if we were mighty men of valor, who must have nought but strong meat and plenty of it. Apparently a whole herd of ancient he-goats had been purchased for our benefit and the "cook" performed further wonders in cooking the meat to degrees of toughness never before dreamed of by our unfortunate teeth. Three times a day we faced the ordeal and this went on for a long week. The manager of the "hotel" was said to be a Greek, but whatever he was he could earn good wages as one of the lesser pirates in Hollywood. There were next to no servants visible, only two miserable little black boys; one boy, named Moki, was arrayed in the most grimy of shirts and short pants; the other little boy wore only a native toga of goatskin but with great dignity. Their cooking, dish-washing and waiting on table had best be left unsung. The manager explained that he could get no other servants, as all the able-bodied men were at work building the new hotel next door. Nobody thought of hiring Negro women as hotel servants. Their place was in the home, where they did the farming and other domestic tasks, including some very sketchy cooking and housekeeping.

At meal times Moki, who had about enough brains to admit him to an imbecile asylum, was the official scapegoat of the establishment. Whenever any one forgot to put a knife or fork on the table or to serve a waiting guest, it was always Moki who was roared at by the pirate-manager. Moki took all the verbal abuse with the stolid placidity of his race, however, and went about his work with an air of dogged resignation. Moreover, Moki had, in my eyes, a great redeeming trait—his muzzle strongly reminded me of that of the pig-tailed macaque.

A week later, when we left the hotel,

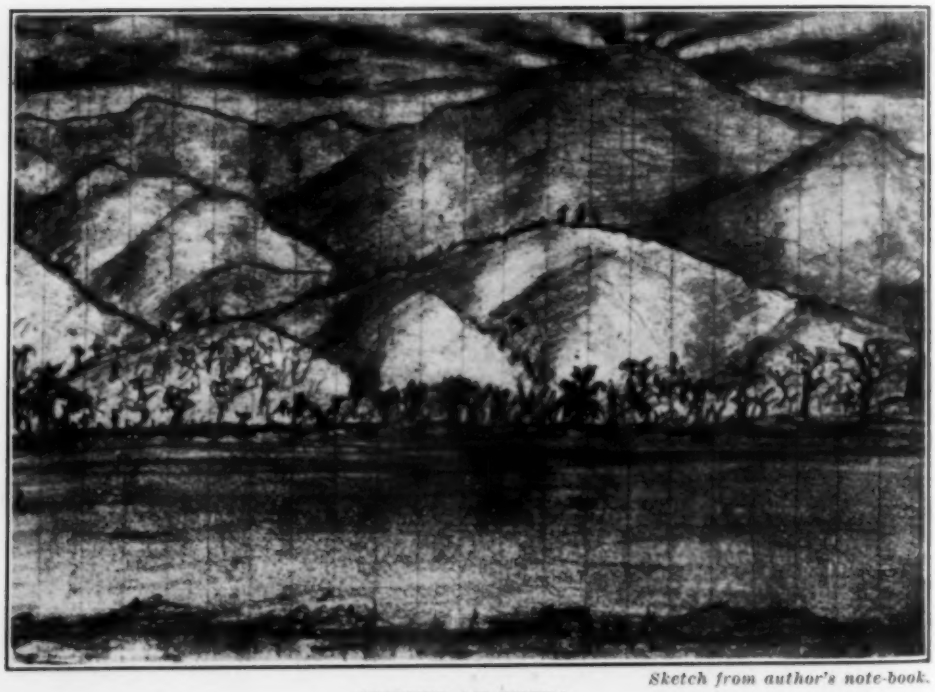


Photograph by H. C. Raven.

BUSH FIRE ON THE HILLS AT BUKAVU, LAKE KIVU

Sketch from author's note-book.

DRAINAGE SLOPES AT UVIRA.



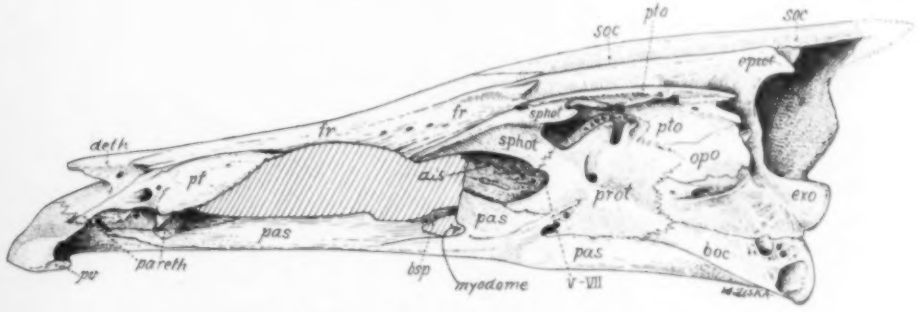
Sketch from author's note-book.

SUNSET AT UVIRA.

we took pleasure in giving Moki, by way of consolation, a tip of enormous size for that part of the world. We have no doubt that he had sense enough to keep it out of the manager's clutches. We never observed that the manager struck Moki, as under the benign rule of the Belgians there is a heavy fine for striking a native and doubtless all the natives know it.

Next morning after our frugal breakfast we went out to see what Uvira looked like in the daytime. Like many other towns in the Congo, it is growing very fast in anticipation of the completion of the railway which is now being built to connect Uvira with the towns to the north on Lake Kivu. Next door a swarm of naked little black boys were gliding forward, carrying little pans of water or small loads of brick on their heads to the masons, who moved with the celerity of half-melted asphalt. The little boys have spindly legs, enormous abdomens and huge, languorous eyes; their faces and bodies are daubed and dusted in the most ludicrous fashion with the mud and plaster amid which they move.

A yoke of oxen has just brought a load of sacks of cement for the building. The oxen have enormous horns which rise up almost vertically above their foreheads. (Afterward I learned that these very long-horned cattle are similar to those figured on the Egyptian monuments and are said to belong to the same species.) They stand there sleepily, submitting most willingly to the services of two industrious hens, who are eagerly picking off the flies and ticks that cluster on the legs, necks and bellies of the oxen. The off-ox even lowers his head, turns it on one side and plainly invites the fearless hen to relieve it of the pests that cling around its eyes. I was full of wonder at this miracle of apparent intelligence on the part of the ox. How did it learn this trick? On many other occasions, however, the answer came readily. African cattle generally, both wild and domestic, are attended from calfhood onward by beautiful white herons, which perch on their back or stalk deliberately about on the ground, and by flocks of pert little ox-peckers, which flutter about and take the most surprising liberties with their gigantic friends. Once we saw an ox-pecker cling to a cow's head and literally climb into her ear in its eagerness to help itself to the delectable feast of flies and ticks.



CRANIUM OF THE NILE PERCH

On Sunday, July 21, 1929, when we were somewhat dismally waiting on the hotel veranda for our Sunday dinner of goat's meat, we received a brief visit from a so-called pygmy, who seemed rather to be a midget or ateleotic dwarf. She was a little old lady exactly three feet, eight inches high, and very fussy and particular in her light calico dress. She had a tiny straight face, an infantile long head and delicate limbs. In my in-

Photograph by H. C. Raven.

LONG-HORNED OXEN AT UVIRA.

nocence I offered her a large safety-pin, hoping that she would thrust it through the base of her nose, but she handed it back with a superior air and held out an insistent palm for francs. She then did a few very formal and deliberate turns and posed for her photograph, standing beside one of our own blond Nordics, winding up the performance with greedy appeals for more francs. She looked ancient, but one of the guests assured us that she could not be more than forty years old, because she said she remembered a certain famous Arab raid that happened when she was a child.

That afternoon I strolled down along the lake shore near the wharf where the boats from Kigoma come in. At that point a stream which has cut its way down through the crystalline mountains has discharged on the lake shore an enormous load of large angular fragments of schist, containing mica, and blocks of feldspar. The waves have had but little effect on these hard fragments, or probably they have broken off all the more friable pieces, shoved them along and ground them up, distributing them as coarse sand on the shores near by. In certain spots these angular fragments are being cemented together by a natural cement into a massive and very hard breccia. At this place I did not know which attractive route to follow: whether to push my way up the rocky gorge, which was highly alluring in its wild confusion and grandeur, or to follow along the shore, which was already yielding its provocative traces of nature's wonder-working.

Here are some of the things I saw along this shore on this and other walks. First, the backbone of a large fish, evidently belonging to the enormous group of the "spiny-finned" fishes; but to which one? A few yards further came the answer in the shape of a sickle-shaped preopercular bone with several large cog-shaped projections on its hinder border. Surely this must be my old

friend *Luciolates* or some near relative. Then a little way further on and there is a glistening white, perfectly cleaned skull of *Luciolates*, which I eagerly grasp, for what osteologist would despise such a gift! In fact this skull afterward proved exceptionally valuable to me, since it so clearly illustrated the details of bone architecture in a typical fish skull. Then I pick up two very beautifully sculptured bony scutes, each about two inches in diameter, which have weathered out from the leathery back of some large crocodile. No wonder the natives keep very close to the shore when bathing! Then many small crabs, the same species as those at Kigoma and closely related to marine types. Then swarms of tadpoles in the tide-pools, getting ready to take their places in the Uvira night choir.

On another occasion I came to a village near the shore of the lake, where most of the folks are basking in the sun, but here are some small boys standing in the water and fishing. These young rascals have been fishing on the Sabbath day with a pole, a bit of string, a bent pin and worms. They come near and show me tiny baskets or old tomato cans containing gorgeous little cichlids and most comely young *Luciolates*. Recklessly I spend my money for each lot, getting six or seven different species for a few Belgian francs (1 franc is about 3 cents). The boys know I am crazy, to pay so much for so few mouthfuls, but I rush off with hands and pockets full, to sketch some of these fish while they are fresh and to get them in formalin soon afterward. I do not mind in the least that probably none of them are "new to science," as the fishes of Lake Tanganyika have been described by several authors. They are all new to me anyhow, and give me my first field-introduction to this famous African family of cichlids.[5]

[5] By a strange chance, however, most of the small fishes which Mr. Raven and I collected in this way proved to be new to our collections at the Museum, and one of them was later described as "new species" by our colleagues J. T. Nichols and F. La Monte.

One afternoon I started northward along the road toward the head of the lake, looking however constantly toward the bare mountains on the left for a favorable place to climb up one of their lower spurs. First I pass through a small and a very soiled-looking settlement of Indian merchants. Here several long-bearded patriarchs with sickly, pallid skin and cold eyes await Nirvana; but meanwhile they despoil the heathen blacks.

Next I come to extensive brickyards, where the natives make huge piles of bricks from the red clay and bake them. Passing through this village on my way up the path toward the mountain, I find many men sitting leisurely in front of their round straw huts and doubtless discussing weighty matters, while the women are out at work. One elderly man starts after me. I know he wants to serve as my guide, but there is no way to go but up and nowhere to come but back, so I wave him off. Blandly and doggedly he follows my footsteps, as many another native is to do in the months to come. So at last I renounce the selfish hope of enjoying the view all by myself and hand him my coat to carry.

The bush fires have swept away almost everything but a few Euphorbias, some of which grow to imposing size and look like gigantic, many-branched candlesticks. In the pale stubble at our feet I find a small "praying mantis," which is of precisely the same color as the straw upon which he rests. I am constantly on the lookout for a snake, partly because I want to see one, partly because I want to see it first! But only a small cast-off snake-skin rewards my search and I attribute to the bush fires the apparent rarity of snakes which I observed almost everywhere we went in tropical Africa.

As we zigzag upward over the yellowish crystal rocks and blackened fields new wildness and grandeur are revealed; the mountains in the rear come into view and lift up their summits, higher and

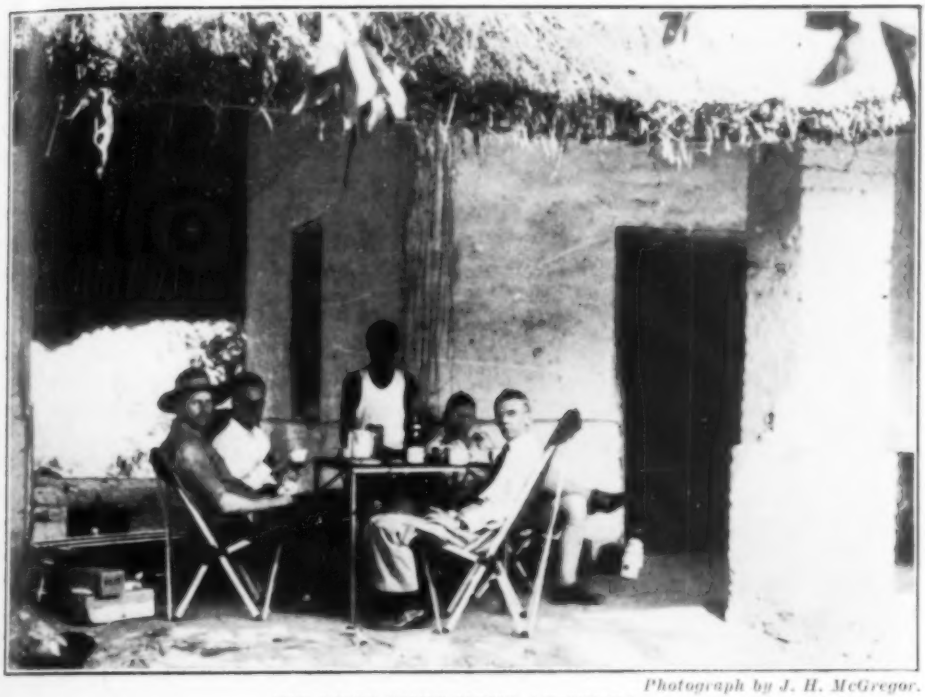
higher; those in the foreground send one jagged crest behind another in long slopes toward the silver lake. I sit down for a while and make a desperate effort to record a few of the crowding mountain profiles in a very crude sketch in my notebook. (This was the first of many that I made on our journey across Africa. No matter how crude they are, they now possess magical qualities since they can instantly carry me back to some soul-filling scene of African mountains and rivers.) I get up and we go on upward; finally we reach the steep shoulder of one of the lower mountains; the sun begins to go down and with half the sky for his background pours forth his most brilliant reds and greens and yellows upon the heaped-up clouds, the jagged mountains and the shimmering lake. The celestial color-symphony mounts to almost insupportable heights and then slowly recedes into myriad purple waves. Reluctantly the spectator descends the open mountain side to the highroad and dismisses his faithful guide with a generous reward.

During the next ten days at Uvira Raven was constantly busy with many tedious but unavoidable duties. First, as Uvira was practically the port of entry into the Belgian Congo, he had to go over his lists of equipment and assign a fair valuation to every foreign article we were bringing into the country, and the customs officer had to ascertain what import tax should be levied upon each article. The whole amounted to many thousands of francs, a sum which, however, was only paid on deposit, practically all of it being refunded when we left the Belgian Congo.

Meanwhile the administrator of the town of Uvira had very kindly placed at our disposal a commodious house and the adjoining grounds, which belonged to the Government. The house had brick walls coated with whitewash; there were broad cool brick verandahs and a thatched roof. Up to this time (July 24) our entire camp equipment had been, as it were, in bond to the customs of the different countries through which we traveled and we had as yet used only the things that were in our personal trunks and hand baggage. At last the time had come to open up all our camp equipment. After our things had been moved from the Customs House to our new temporary home, Raven, assisted mostly by Engle, selected the stuff necessary for our coming trip into the mountains west of Lake Kivu, storing away the supplies for our future trip down the Congo. For the present trip hundreds of things were necessary: for injecting and preserving specimens, for photography (movie and still cameras, several kinds of negatives, chemicals, portable drying frames, etc.), medicines, firearms, ammunition, bedding, folding chairs, cooking utensils, etc., etc.—all to be packed, catalogued and arranged for accessibility in boxes and bundles just big enough to be carried on a black man's head up mountain trails.

Then as soon as we could obtain three good boys as servants, we set up our camp beds and mosquito nettings on the porch of this house and took joyful leave of the Greek and his hotel. We immediately celebrated Dr. McGregor's birthday with a fine camp dinner, including excellent soup, roast chicken, salsify and bacon, home-made bread, white wine and real tea—a refreshing contrast to the devastating fare of goat's meat at the hotel.

There were many beautiful mango and other trees on the grounds in front of our house, which overlooked the lake shore. Here in the daytime fair-sized agamid lizards with spikes on their heads raced up and down the tree trunks and ant-lions laid in wait for their prey in conical depressions in the ground. I had an unfortunate experience with one of these lizards while photographing him—unfortunate for the lizard, that is. The poor thing was tied with a string and in



Photograph by J. H. McGregor.

WE DINE CHEZ NOUS AT UVIRA

its frantic struggles to escape, snapping its jaws and running hither and thither, it soon became sunstruck and died. I should have remembered that a reptile is much inferior to a mammal in its ability to keep the body temperature from rising beyond the danger point.

At night we would creep out under the trees and then, turning on our flashlights and looking along the barrel, we saw at different times the lamp-like green eyes of a small antelope, the glowing red eyes of a civet cat, the small green eyes of fruit bats. The latter flitted about in great numbers, their black wings outlined against the moonlight.

As the mountains cooled off, the air upon them grew heavier than that above the water and a cool breeze swept down toward the lake, which made our blankets very acceptable at night.

In one of the inner rooms of our house Dr. McGregor and the others developed their photographs at night, disputing possession with the enormous cockroaches that swarmed over the walls. McGregor was delighted with these insects, which showed many stages of development from the egg upward. They are, it is true, among the most ancient of "living fossils," remains of their ancestors being found in the rocks dating from the Carboniferous period; nevertheless, I was slow to give up my ancient grudge against them. Raven was inclined to take McGregor's side of the argument, but later when, in the middle of the night, one of these ravenous beasts had given him a good bite on the top of his head, thereby marring its orb-like splendor, his manner toward them (to judge from his remarks) seemed less cordial and appreciative. Ingenious devices had to be adopted to protect the washed and drying negative strips from being nibbled by these voracious animals.

While we were at Uvira we had the pleasure of meeting Mr. G. B. Murphy, a

young man who had been sent from the department of birds in our Museum to conduct collecting expeditions into various parts of equatorial Africa. He was just returning from the mountains to the west of us at Uvira and had secured there some excessively rare species of birds for which he had been especially searching. He told us one incident of his journey that illustrates some peculiar traits of the African character. He had arrived at a certain village, where he had requested the chief to supply him with porters. The chief had assembled the available men and ordered one after another to go with the white men. One big man said "No, I will not go." "You will not?" asked the chief. "No, I will not." At the chief's orders he was seized, bound and lashed until the blood ran from his back. "Now will you go?" asked the chief. "No, I will not," replied the man. Again he was beaten, more cruelly than before. Again he was asked whether he would go, and again he refused. It was not until the end of the third beating that his spirit was broken and he said he would go. In a day or two, when they were ready to start, this big man stood in line, took his load on his head and served well throughout the trip, bearing no grudge against the white man.

At last our arrangements were sufficiently completed at Uvira and it was decided that Dr. Engle and I should go ahead to Bukavu (Costermansville) at the southern end of Lake Kivu, while Raven and McGregor would follow in a few days. Although Lake Tanganyika is one of the highest lakes in the world, Lake Kivu, the next one to the north in the series of Africa's Great Lakes, is some two thousand feet higher. At the southern tip of Lake Kivu the surplus water of the lake drains off to form the Ruzizi River; this river breaks through the volcanic mountains south of the lake and runs southward into the northern end of Lake Tanganyika. The Belgians, who are the greatest road-builders since the Romans, have constructed a good road along the Ruzizi Valley so that commerce can flow north and south between the Belgian Congo and the rich countries around the headwaters of the Nile. Camions driven by Portuguese and Negroes make this trip two or three times a week.

At about 4 A. M. on July 25, 1929, a big camion stopped at our house in Uvira, our baggage was quickly stowed aboard and Engle and I climbed up into the seat with the black driver. As we bounced over the rocky road before daylight our flashlights revealed many natives, both men and women, carrying huge loads of cotton and other products in great baskets on their backs or in bales on top of their heads, trudging along toward Uvira, either to sell their goods in the market-place or to take them to the wharf for shipment south and east.

Gradually the road twisted and turned as we climbed to higher levels. Just after dawn we overtook another camion which had stalled, and our chauffeur spent nearly an hour fixing its carbureter, while we walked up and down on the high plateau to keep warm. The sun meanwhile came up in all its splendor, revealing crystalline mountains on both sides of us and the lake to the south. On this plateau the flat-topped acacias of East Africa were in evidence, amid large fields of stubble. The ground was made up of thick alluvial deposits of pebbles and coarse grit, brought down long ago from the mountains and distributed over this broad valley by the Ruzizi River and its tributaries, which have now worked themselves down to deeper levels. On the ground in the stubbly field I found many scattered rings of cuticle about the size of wedding rings. These puzzled me at first, but soon I found that they were segments from the cylindrical, many-jointed body of a large milliped. These beasts are greatly dreaded by both whites and

blacks but are entirely innocuous. Many quaint old men and women passed us while we waited, plodding along with their burdens. The men often carry spears with long slender iron tips, like those of the Masai lion-hunters; they walk erect and carry their loads on top of their heads. The old women carry enormous loads of cotton or other products on their backs, leaning far forward and supporting themselves with a stick. They carry their wealth on their ankles in the form of copper or iron wire anklets. One poor old beldame with deep wrinkles all over her face and purse-like breasts hanging down to her waist had enough of these iron wire anklets on her to tire an elephant.

Resuming our way northward we passed on our left many crystalline mountains, whose contours resembled those around Uvira. We stopped for breakfast at about nine o'clock at the small inn at Luvunghi. It was a brick building in the Arabized African style with arched porches and inner court. The circular thatched straw huts of the natives are surrounded by a flimsy stockade of Euphorbias; tiny gecko lizards run up and down these prickly thoroughfares. In the road a native sits basking in the sun and tinkling his "box-piano" (lukimbe). This instrument consists primarily of a graduated row of iron strips fastened on a resonating box hollowed out of a block of wood by means of a red-hot iron. Shells or small coins are loosely attached to the iron strips and rest on the box, producing a rattling and buzzing sound that is dear to the native ear. Rapid arpeggio movements are executed as the fingers are swept along the lower ends of the metal rods. Complicated rhythms are woven into the arpeggios, and this instrument affords a convenient medium for the expression of "everyboy's" native talent. Two vultures are soaring above us with all the ease and nonchalance for which they are famous.

This place is near the middle of the broad valley, south of the pass through the mountains. Antelopes and elephants are said to be common near here. Some distance beyond Luvunghi we forded the Ruzizi River at a point where elephants frequently came to drink.

After we passed this ford we began to wind our way up into the mountains and our spirits rose steadily with the altitude. Immediately below us the river appeared as a silvery path, meandering over the broad plain; further up the river we could see with our glasses the rapids

Photograph by author.

AGAMID LIZARD.

where it struggled over the blocks which it had itself brought down from the mountains, while far to the north was the deep notch by which it had eaten its way through the mountain barrier as it worked its way southward from Lake Kivu. At this time we were still well below the level of the summits of the ancient crystalline mountains which we had been passing on the way north, and as the road wound upward we were rising from lower to higher levels of the inconceivably ancient foundations of the continent. Evidently we were in a region where there had recently been an immense upthrust, for the process of erosion had not had time to soften the incredibly steep and jagged contours.

Our exhilaration amidst this tremendous evidence of earth history was by no means checked by the dizzy turns the

road was making, often on narrow ledges from which one could gaze down plunging declivities that converged toward the shadowy abyss below. One false turn of the wheel by our black chauffeur and we should catapult through the flimsy wall and do a dazzling series of somersaults to some sudden stopping-place on the way down. But our black was doubtless well used to the giddy contortions and instantaneous shifts of the native dance and in this dance of the camion he and the camion were one. After we came up to a comparatively smooth stretch he lit a cigarette with all the nonchalance of an English speed king.

Then came a very long pull upgrade, during which we passed hundreds and hundreds of blacks working on the road. Each one was slowly carrying a tiny basketful of earth or a couple of rocks on his head, but the cumulative labors of these human ants had built this more than Roman highway through the mountains. How tantalizing it was to whirl past this inspiring panorama of human faces, each one with its unique individuality, and to be allowed to snatch only a fleeting glimpse of them.

By and by we came to another camion which had butted its face into the rock of ages without visible damage to the rock. This excited the professional interest of our black jehu, as it gave opportunity for *un gros palaver*.

Accordingly Dr. Engle and I had a chance to take our cameras and walk up to the next protruding tower, which commanded a superb view of the winding river beneath and of the far more precipitous mountains to the north. Apparently we were still below the summit of the old crystalline Archean formations, but there to the north of us we were confronted by threatening outposts of once molten rock, which had burst upward from some vast reservoir below. When this had happened the foundations of the continent had been shaken and

Photograph by E. T. Engle.

EXPEDITION TRUCK UNDER REPAIRS, ON PLATEAU NORTH OF LAKE TANGANYIKA

Photograph by H. C. Raven.

RUZIZI RIVER, SOUTH OF LAKE KIVU.

shattered, permitting enormous earth blocks to settle and pushing others up to precipitous heights. Had this great disturbance been at the time of the formation of the great rift valley or was it of later date, like the very recent volcanic outpourings north of Lake Kivu? Was it this disturbance which had blocked the southern exit of the old Kivu rift valley and thus caused the gradual filling up of the valley by the lake? And then had the Ruzizi River, starting from the overflow of the lake, gradually worked its way south and then dug down until it poured the overflow from Lake Kivu into Lake Tanganyika?[6]

These reflections were interrupted, however, by the arrival of our camion, and Dr. Engle and I regretfully turned our backs on the marvellous scene. Then we began to climb to still greater heights, up over a stupendous gray conical mountain that seemed to be of very recent volcanic origin.

At intervals as we wound around the spiral path, a waiting native would sound a horn, beat a can or hoist an old petrol tin on a high hill, as a signal that the

[6] According to the Encyclopaedia Britannica (14th Ed., 1929, article on Tanganyika), the northern continuation of the Tanganyika rift valley is "suddenly interrupted by a line of young eruptive ridges which dam back the waters of Lake Kivu but have recently been cut through (in about the year 1906) by the outlet of that Lake, the Russisi, which enters Tanganyika by several mouths at its northern end. The flat plain traversed by the lower Russisi was evidently once a portion of the lake floor." According to Dr. Bailey Willis ("Living Africa," p. 121) also: "The Ruzizi drops twenty-six hundred feet from Lake Kivu to Tanganyika, practically all of the fall being in the upper half of its course. Considered as a river, the Ruzizi is but an infant. Not long ago Lake Kivu (or rather the valley it fills) drained northward to the Nile. But volcanoes arose along its course, their lava flows laid a dam across the valley, and it became a lake basin. In a few decades the waters rose to a low pass at the southern end, flowed out there, and produced the Ruzizi river. Its deep gorge is a fine example of youth."

Photograph by E. T. Engle.

ROAD BUILDERS ON THE ROAD TO LAKE KIVU.

Photograph by H. C. Raven.

MOUNTAIN SOUTH OF LAKE KIVU.

road was clear. One could not help wondering what would happen if one of these black traffic cops made a mistake and allowed a descending camion to meet us on the one-way track. But the opportunity of making an exceptionally loud noise by beating the signal-can was too good a one for a native to miss.

On some of these heights, which were almost bare of vegetation, one could look to the north and see the mountains around the southern end of Lake Kivu, wave after wave, as if the earth had liquefied under some stupendous impact. More probably it seemed, the wave-like appearance was due to erosion, by the present drainage system, of an old mountainous district that had been reduced, by an earlier cycle of erosion, to a peneplain or generally flat level.

In this region, which has been subjected to such enormous disturbances, one may be passing at a certain time over a huge block that belongs to the later or volcanic invasion, and a little later, although then further to the north, one may be passing over a block of the far older "crystalline" series belonging to the south; but as one passes beyond the zone of maximum disturbance, the outliers of the older formation become scarcer and one is at last fairly within the zone of the later formation. Thus, as we approached Lake Kivu, the yellowish gneiss-like rocks of the Uvira district became rare, the gray material that we had just passed diminished and we came into the zone of the dark-red soil of the Kivu region.

About twelve o'clock that morning we were winding up and down at high levels along the upper valley of the Ruzizi, passing mountains with boldly serrate and irregular contours which graded southward from the wave-like form, of which we later saw so many around the lake, into the bold jagged cones of gray volcanic material mentioned above. Then we came to hills in which the underlying country rock lies beneath a thick mantle of red soil, which may be the product of the disintegration of the crystalline rocks. After winding down past many bare red hills dotted with long-horned cattle, banana plantations and native huts, we sloped upward a few moments, suddenly drove out on to the long promontory upon which Costermansville (Bukavu) is perched and stopped in full view of the narrow southwestern end of Lake Kivu.

THE APPROACH TO THE ABSOLUTE ZERO OF TEMPERATURE[1]

By Dr. F. SIMON

CLARENDON LABORATORY, OXFORD UNIVERSITY: FORMERLY PROFESSOR OF PHYSICAL CHEMISTRY AT BRESLAU

SPEAKING in this building, with all its associations with low temperatures, a long introduction would be superfluous, but I would like to remind you of some data. In Fig. 1 a temperature scale is given in degrees Centigrade, and you see some important fixed points marked on it.

Now is this scale infinite at both ends or not? We know that heat consists in the unordered motion of the smallest particles, the atoms or the molecules, and the intensity of this irregular motion rises with increasing temperature (in an ideal gas it is directly proportional to it). So it is evident that there will be no limit to high temperatures, as there is none to the intensity of the motion, but of course, there will be a lower limit to the temperature scale, at the point where the thermal motion stops altogether. This point is therefore with justification called the absolute zero. Though it has not been reached in experiment, and as we will see later on, it is by principle impossible to reach it absolutely, its position can be given with great accuracy, and it is found to lie at −273.1° C. A rational temperature scale has, therefore, to begin at this point. In this scale, the Kelvin scale, the absolute zero of temperature is given by the number zero, and any other temperature by adding 273.1° to the number of degrees Centigrade. On the right hand side of Fig. 1 the temperatures are indicated in degrees Kelvin, and you see that the boiling point of the most volatile gas, helium, lies about 4° from the absolute zero. In Fig. 2 you see the liquid helium range given in more detail. By reducing the pressure over the liquid helium, one can easily get down to about 1°. By improving the isolation, and using a huge pump, Keesom succeeded in reaching 0.7°, which was the lowest temperature obtained until a few years ago.

I will begin by showing two experiments. The first is the production of a high temperature. It is a very simple experiment that you have all done yourselves. I need only switch on an electric lamp. By varying the current I get temperatures up to 2,500°.

In the second experiment I will generate a very low temperature, and that is much more complicated. While I could certainly perform the first experiment without any help, the second would be impossible without the kind help of Mr. Green, Dr. Kürti, Dr. London and the staff of the Clarendon Laboratory, who have all helped in its preparation. We will now liquefy helium, making use of a principle about which I will say something later. Now I should like to point out that we start at a temperature obtained with solid hydrogen (about 12°), that within the apparatus there is helium compressed to about 100 atmospheres at this temperature, and that the helium will be expanded into a balloon, where we will store it. During the expansion the helium will liquefy and reach its boiling temperature, 4.2°. As the helium is enclosed in a metal vessel, I will not be able to show it to you, but even if I could, it would not look a bit colder than

[1] Presented at the Royal Institution of Great Britain at one of its weekly evening meetings, in February, 1935.

liquid air. This simplified gas thermometer gives you a much better measure for the temperature. You saw that it pointed first to 12°, then, as the helium was expanded and this balloon filled, the temperature fell to about 4°. I can also show you another proof that we have reached the temperature region of liquid helium.

You have all heard of supraconductivity. This is the name given to the phenomenon discovered by Kamerlingh Onnes, that at certain temperatures some metals lose their electrical resistance altogether. The temperatures at which this happens are very low, they all lie below 10°. In a normal substance a current once induced would disappear very quickly, as its energy would be absorbed within about 1/1,000 of a second by its resistance. In the case of a supraconductor, however, there is no resistance, so that the current goes on flowing indefinitely.

In this lecture room, Professor McLennan[2] showed you this phenomenon of a persistent current in a lead ring, which was brought from Leiden immersed in liquid helium, so I need not speak about it in detail now. For the moment we will only use it to show that we really have the temperature of liquid helium. For this purpose a lead ring is fixed within the apparatus. Lead becomes supraconductive at about 7° so that now at 4° it is already in the supraconducting state. We will now induce a current within this ring.[3]

Before the current was induced a magnetic needle was not affected. Now you see that when I hold it a little above the ring it points with its N pole towards it. This indicates that there is a S pole of the magnetic dipole corresponding to the persistent current. Bringing it below the ring, it naturally changes its direction.

I can show you the existence of this current in yet another way, I have here a small coil connected with a galvanometer. When I bring it up to the apparatus, you see a ballistic deflection of the galvanometer. This is due to the cutting of the magnetic lines of force originating in the persistent current, and the magnitude of this ballistic deflection is a measure of the intensity of the current. So we have here a quantitative measure for the current, and we will verify at the end of the lecture that it is steady.

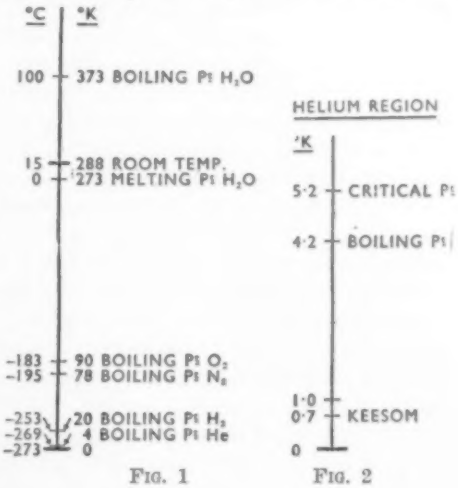


FIG. 1 FIG. 2

You see the great difference in outlay for the two experiments. For generating 2,500° you have only to connect an electric lamp to the mains; for generating −270° you have this decidedly complicated apparatus—and yet this is certainly the most simple one in existence. And we have not yet even taken into account that in the second experiment we did not start at room temperature, but at −260°. This temperature was obtained by hydrogen which we liquefied in the plant in the Clarendon Laboratory in Oxford, and the liquid nitrogen neces-

[2] *Proc. Roy. Inst.*, Vol. XXVII, p. 446, 1932.

[3] This was performed by switching on a magnetic field, higher than the threshold value of lead at this temperature, so, with the field on, no persistent current flowed; reducing the field, a current is induced, which now persists as the substance is in the field zero.

sary for the hydrogen liquefaction was generated in yet another plant. For the first experiment, on the other hand, I could get the whole plant in my hand by taking a torchlight.

Now what makes this big difference? Heat is due to the irregular motion of the smallest particles. So to heat a substance means to increase its energy, but still more to increase the internal disorder of its particles. To cool down a substance means to diminish its energy, but still more to increase the internal order of its particles. For example, a gas is in a very big state of disorder, the atoms flying in all directions about the space according to their kinetic energy, which is proportional to the temperature. Cooling it down, it will first liquefy, and a liquid is already a much more ordered system than a gas. Cooling it still further, it will solidify; now all the mean positions of the particles are given by a crystal lattice, and the system is in a state of nearly perfect order, only the thermal vibrations of the atoms around their mean positions being still a source of some disorder. Cooling down still further, even this disorder vanishes more and more.

So cooling a substance means bringing it into a state of order, and it is always much easier to make disorder than to establish order. Although you are certainly very familiar with this fact, I will illustrate it by an example. On this tray I have arranged these black and white balls in order. It is very easy now to establish a disorder by shaking the tray, but it is impossible to establish any sort of order again by shaking, or to speak more precisely, the probability of succeeding is extremely small. Of course, I can establish an order by selecting the balls with my hands, but in the case of a system consisting of atoms, this is obviously impracticable, and by principle impossible too. We have only macroscopic means at our disposal. This difficulty of creating order is just what makes the big difference. And this is why, even 10,000 years ago, men were able to generate very high temperatures —sufficient for melting metals—but the low temperature technique is of a quite recent date. Even the ice cream industry is fairly new, though the temperatures involved are not very much below room temperature.

To generate heat one must, of course, have energy at one's disposal, but to transform this energy into the disordered form of heat energy presents no difficulty at all. We saw this in the electric lamp, but one can do it in a great many other ways; for instance, in a candle it is a chemical energy we transform into heat energy, in the brakes of a car it is a mechanical one.

If our example with the balls were absolutely analogous, it would be impossible to generate a low temperature at all, but luckily it is not so, because, unlike our analogy where the order depends only on one variable, in a real physical system it depends on many more. The most important quantity it still depends upon is the volume. Taking the probability of finding an atom within a certain region as a measure for the state of disorder respective to the positions in space, it is quite evident that this probability decreases on enlarging the space the atom has at its disposal. So in a diluted gas we have a great disorder; if it is compressed to a small space, its order is increased.

Now thermodynamics has given us a quantitative measure for this state of order of which we have to speak so much now, since it is necessary for understanding things later on. This measure is called the entropy. I will not trouble you with this quantity, as I know it is not a very popular one. I only want to remind you that it is a measure for the state of order, and that there is a law, namely, the second law of thermodynam-

ies, which tells us that within a closed system during any change the entropy can only increase, or at the best by making a reversible change (that means avoiding unnecessary disorder) it can remain the same. Speaking in our terms now, this second law means that in a closed system the state of order can only decrease or at the best remain constant.

Let us see now what this has to do with generating low temperatures. We will take a cylinder with a piston, containing a gas, the whole system being perfectly isolated from its surroundings. The state of order in this system consists of two parts, one depending on the temperature and the other on the volume. Compressing the gas, we increase the state of order corresponding to the volume. As the whole state of order must remain the same, the disorder due to the thermal motion has to increase, that means the temperature rises, and you all know that in compressing a gas it heats up, this heat being called the compression heat.

Bringing this system into thermal contact with its surroundings, it will cool down to the initial temperature, and so its disorder becomes smaller. But of course, that does not contradict the law I spoke of before, because heat is transmitted to the surroundings, so increasing the disorder of the particles there.

Now we will isolate the system again and pull the piston out. The part of the disorder due to the volume increases again. The whole state of order must remain constant, so the part of the disorder due to the temperature must fall, and that means the temperature itself falls.

That is a characteristic example, and one of the most important cases of how to generate a low temperature. Generally speaking, whenever one wants to lower the temperature, one must have a system in which the state of order can be changed by some external means. Then in the way described above, one is able to transmit a part of the original disorder in the system to the surroundings, and to cool it down, making the same change of this variable in the opposite direction after having isolated it from the surroundings.

Gases are the prototype of a disordered system, the existence of which is necessary for the procedure of generating low temperatures, and it is relatively easy with them to change this disorder by changing the volume. So practically all procedures for generating low temperatures were worked with gases until recently. Of course, one can make use of them only down to the temperatures at which they liquefy, or more precisely, as long as their vapor pressures have still practicable values. So in practice the generation of low temperatures and the liquefaction of gases have become practically identical conceptions, and every step towards a lower temperature has been marked by the feat of liquefying a gas with a lower boiling point than was previously possible.

I will not speak now of the development of the real procedures performed with gases in order to liquefy them, which, for technical reasons, have to be much more complicated than the example I gave you. I need only remind you of the names of Faraday, Cailletet, Pictet, Olzewski, Linde, Hampson, Dewar, Claude and Kamerlingh Onnes. You know that it is now relatively easy to get down to the temperature of liquid air, as the liquefaction of air has become important for industrial technique. But I want to mention that to cool by one calorie, at even such a relatively high temperature as that of liquid air, is already 500 times as expensive as to heat by a calorie above room temperature, for instance, by burning benzene. But at lower temperatures the difficulties increase enormously, so that the use of liquid hydrogen has been restricted to a few laboratories, and that of liquid

helium to still fewer big specialized laboratories.

In recent years the study of the properties of matter at very low temperatures has become increasingly important, and so, of course, one has sought for ways of simplifying the low temperature technique. We have in the last few years developed a comparatively simple method for liquefying helium, which I have shown you already, and now I should like to say a few words about it. The procedure of expanding a gas in a cylinder, in the way already described,

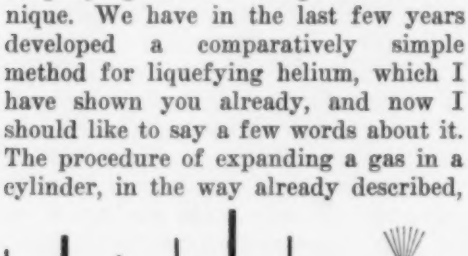


FIG. 3. PRINCIPLE OF THE EXPANSION METHOD.

is very simple. But at very low temperatures it is difficult to realize technically a cylinder and a piston.

But one can overcome this difficulty in a very simple way, which I will now explain. In Fig. 3 A we have a gas enclosed in a cylinder with a piston. Pulling out the piston, the gas will cool down. In Fig. 3 B you see the cylinder divided into two parts connected by a tube. Pulling out the piston now, the gas will cool everywhere, because this cooling is an homogeneous procedure. Let us cool now only the lower part to the low initial temperature at where we start (for example, to the temperature of liquid hydrogen if we want to liquefy helium); leave the upper part at room temperature, and pull out the piston again. Then the gas will cool down within the lower part, the same as if the upper part were at the low initial temperature too. The atoms in the lower part do not know whether the upper part is hot or cold and the atoms do not know either if there is a cylinder and piston outside. We get the same effect if I simply let it out by a valve, as in Fig. 3 C. I want to emphasize that the cooling arises within the cylinder, and not at the valve, as in the Linde process. The procedure described above has nothing to do with the Linde process, but it has more resemblance to the Cailletet method. You remember, perhaps, that he let a gas expand in a glass capillary tube, and with some of the so-called permanent gases, he could then see a little dust of liquid drops, indicating that for some fraction of a second the temperature had fallen considerably.

Now starting at high temperatures, the cooling effects obtained in this way are very small. The chief reason for this is that a container for high pressures has, at room temperatures, a heat content that is always big compared with that of the gas. Starting at low temperatures, however, the situation changes absolutely. Firstly, one gets a much bigger amount of gas into the container at a given external pressure, according to the gas laws, and secondly, the specific heats of all solid bodies drop with temperature, disappearing on approaching absolute zero. So for instance, at a temperature of about 12°, 1 cu. cm. of helium gas compressed to 100 atmospheres has the same heat capacity as 1 kilogram of copper. This means we can neglect the heat capacity of the walls altogether, and we have the advantage of working with mathematical walls. Thus the efficiency of the procedure as I described it to you becomes very high, and working with suitable dimensions and a good isolation, it is easy to keep the low temperatures too. For instance, under the conditions

realized in this apparatus, about 60 per cent. of the volume originally filled with the compressed helium remains filled with the liquid phase, and in the apparatus we generally use we can raise this efficiency still much higher.

In this way one could liquefy any quantity of helium. But as the specific heats at low temperatures are so very small, only tiny amounts of liquid helium are really necessary for cooling down the apparatus and making measurements for a number of hours, if the apparatus is designed in a suitable way. For example, in this apparatus we have liquefied about 50 cu. cm., which is sufficient to cool down the whole system and to work for about five hours.

In Fig. 4 you see a rough plan of the apparatus. Outside is the vessel D with liquid hydrogen; inside, the space S that is evacuated. Within this you see the container C that is first filled with compressed helium, and after the expansion with liquid helium. Attached to this container is a gas thermometer G, the readings of which you saw before.

To cool the apparatus down further, one could reduce the pressure over the liquid helium; the temperature must then fall till it corresponds with the vapor pressure of the helium. For purely technical reasons we do not do this, but we have a second vessel E that we can fill with liquid helium by letting helium gas through the tube T. Then it condenses in the tube T where it is in contact with C, and drops down into the vessel. By pumping through T now, we reduce the vapor pressure, and therefore the temperature falls. This vessel and the surrounding Dewar vessel are of this peculiar shape because we will afterwards apply magnetic fields to some substance situated in the vessel, and of course, one can generate strong magnetic fields over a small distance more easily than over a big one. Now we will pump off the helium in this vessel, in order to reduce the temperature here, and the temperature will fall below 2° within a short time.

Before we consider the methods of generating still lower temperatures, I want to refer briefly to the measurements of these temperatures. You know that in general one measures temperature by the pressure of a diluted gas, using it as a substitute for an ideal gas. But at the

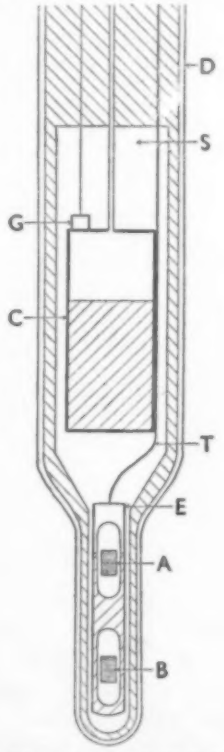


FIG. 4. SIMPLIFIED DIAGRAM OF THE APPARATUS.

lower limit of the liquid helium range the only existing gas, the helium, is stable only at a pressure so small that it is of no use for a thermometer. In this region one can use another phenomenon for measuring the temperature.

The thermometer that I want to speak of now is a magnetic one, and it depends on the fact that paramagnetic susceptibility is a function of temperature. In a paramagnetic substance there exist little

elementary magnets, which we will assume for the moment to be perfectly free to point in every direction in space. The thermal agitation has the effect of making the directions of these elementary magnets have a random distribution. Applying a magnetic field, it will try to turn them in its direction; on the other hand, the thermal agitation tries to establish a disorder with respect to the direction of the dipoles. There will be a compromise of these two effects, and it is evident that the lower the temperature, that means the lower the thermal agitation, the more magnetized the substance will become. Calculating this numerically, one finds that in such a substance the magnetic susceptibility would be proportional to 1/T. That is the famous Curie Law, which was derived primarily for paramagnetic gases, because there the single elementary magnets connected with the atoms or molecules are certainly perfectly free. At first sight one might think that within a solid body the condition of free elementary magnets could not be realized. But experiments, made chiefly in the Leiden Laboratory, have shown that there are some paramagnetic salts which follow Curie's law down to the helium temperatures with great accuracy, and this means that the elementary magnets within them have a very high degree of mobility. The salts concerned are especially those of the rare earth and iron groups. I can not go into a theoretical explanation of this behavior, but I want to mention that it is in accordance with our theoretical ideas.

So it is easy to construct a thermometer with such a paramagnetic substance, using its susceptibility as a measure for the temperature. And it is evident that a thermometer of this kind becomes very sensitive at low temperatures. For example, between 4° and 1° the susceptibility changes in the proportion 1:4. We have a thermometer of this kind in our apparatus. We measure the susceptibility by bringing a system of two coils around the place where, inside the apparatus, the salt is situated, and sending an alternating current through the primary coil; the induced e.m.f. in the secondary depends on the susceptibility of the salt which is fixed within these coils. This induced e.m.f. is amplified in a little set (which the Cambridge Instrument Company have very kindly lent me for the demonstration), then it is rectified and sent to a galvanometer that shows the deflections on this scale. Of course, the system is compensated in such a way that the deflection zero corresponds to a susceptibility zero within the coils. Thus the deflections on the scale are a direct measure of the susceptibility, and as this changes with 1/T, the deflections are proportional to 1/T. At the moment the thermometer is showing about 2°.

Now we can continue considering how to approach nearer to the absolute zero. As I have mentioned already the lowest temperature reached by reducing the vapor pressure of liquid helium is 0.7°. At this point the vapor pressure is so small that it is in practice impossible to proceed further. A gas with a still lower boiling point does not exist. Very probably the new helium isotope, helium 3, discovered in the Cavendish Laboratory, will be more suitable for reaching low temperatures, if it can ever be obtained in sufficient quantities, but there will be no difference in the order of magnitude.

You may be wondering why we should bother to get still nearer to absolute zero, as it seems so difficult now to get down any further. What can still happen in this small region? To answer this question, we have to ask another. When can one predict that something will happen in a certain temperature region?

Let us assume that the phenomenon we are interested in is connected with an energy change of a certain quantity.

Then the thermal agitation will have an influence on it when it itself reaches this order of magnitude. So we see that from this point of view, there is no sense in speaking of an absolutely high or an absolutely low temperature; it is always necessary to compare it with the phenomenon in which we are interested. For instance, room temperature is a very low temperature if we look for the evaporation of diamond, because its heat of evaporation is very high (*i.e.*, only at high temperatures is the thermal agitation big enough to push a carbon atom out of the crystal). But room temperature is a very high temperature if we look for the evaporation of hydrogen, as its heat of evaporation is very small. So the question is, are there any phenomena connected with very small energy changes, that means, phenomena which will still happen at very low temperatures?

If the atoms were only points possessing attractive or repulsive forces, then certainly nothing much of interest would happen within the new region. The thermal agitation would become smaller, but this would not give rise to any new phenomena. However, we know that although in the kinetic theory it was for a long time sufficient to treat the atoms as points with attractive and repulsive forces, yet this is certainly not a complete picture. We know that the atoms are built up from nuclei and electrons. In general one is accustomed to find the effects of this complexity of the atoms only in gases at high temperatures, as most of them are connected with big changes of energy. It is true that at normal temperatures the effects originating in the complexity of the structure of the atom are not very striking in a solid body, but certainly some do exist. For instance, we spoke just now of the magnetic properties of some salts. If the atoms were only points with forces, they could not show any magnetic properties. These are due to the motion or the spin of the electrons, and here we have one effect of the structure of the atom. We have seen already that this effect becomes more and more striking as the temperature is lowered. We have also considered another phenomenon that would not have been possible if the atoms had only been points. A system of points could not show metallic conductivity. That is due to electrons split off the atoms within the metal, and we have seen that with these electrons, something happens only at very low temperatures, namely supraconductivity. Here some change takes place connected with an energy difference of such an order of magnitude that it becomes equal to the thermal agitation only at very low temperatures; and I may mention that at present it is not known what exactly is happening in the metal. It would be very important to see whether, at still lower temperatures, all metals become supraconductive, that is, whether it is a general property of all metals.

So we see that it is of interest to extend our temperature range to lower temperatures, and we will find later on that there are still more phenomena that can be expected to take place below 1°.

But in order to go lower, how can we proceed? As we discussed before, to get a low temperature, one must have a system at one's disposal which is still in a big state of disorder, and one must be able to change this disorder by changing an external variable. At these temperatures we no longer have gases. What other disordered systems still exist? Well, we have just seen one, namely, the paramagnetic salt which still follows Curie's law, and about ten years ago Debye and Giauque proposed using this for the generation of still much lower temperatures.

To understand the principle, look at Fig. 5, which represents a paramagnetic salt. The circles represent the atoms

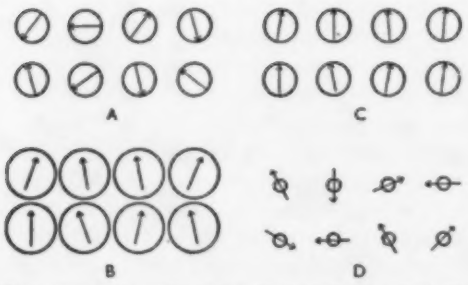


FIG. 5. PRINCIPLE OF THE MAGNETIC COOLING METHOD.

arranged in a crystal lattice, and the little arrows represent the magnetic moments attached to every atom. Without a field (Fig. 5 A) there exists, as we saw before, a random distribution of the directions of the dipoles, so the disorder in this system consists of two parts; one is due to the distribution of the directions of the dipoles and the other to the thermal motion of the atoms. (The diameters of these circles indicate the magnitudes of the vibrations and give also in this way a measure for the disorder to the thermal vibrations.) Applying the field now (Fig. 5 B) it will try to order the directions of the dipoles. Making it adiabatic, that is, having the system isolated thermally from its surroundings, the whole state of order should remain constant, which means that the disorder due to the thermal movement must increase, in other words, the temperature rises (corresponding to the compression of the gas in our former example). Making heat contact with the surroundings the system cools down to the initial temperature, so that now the state of order has increased (Fig. 5 C). Now, isolating the substance from the surroundings, and taking the field away, the dipoles try to distribute their directions at random again, the disorder due to this increases, but as the whole state of order must be constant, the temperature must fall (Fig. 5 D). (Corresponding exactly to the adiabatic expansion of the gas.)

Within the last few years this method has been used experimentally, and at nearly the same time Giauque in California, de Haas in Leiden and Dr. Kürti and I began to work with it. We developed the technique so that it is now fairly easy to work with this procedure, and we can show you an experiment with it here in this room.

We will look once again at Fig. 4. There you see within the lower vessel two different paramagnetic salts A and B, so that we can do two different experiments. To carry out the cooling by this method, one has to have the substance in thermal contact with the surroundings when the field is switched on, and isolated when the field is switched off. We do this automatically by suspending the substance in a little glass tube closed at both ends and filled with about 1 cm helium at room temperature. This gas makes a heat contact with the surrounding helium bath during magnetization. Switching the field off the substance cools quickly, and the helium gas has to condense on it, as the vapor pressure falls rapidly with falling temperature. Choosing the right dimensions and vacuum conditions, one can in this way use the cooling substance itself as a pump.

Now we will begin with an experiment[4] taking first the upper substance, A, manganese ammonium sulfate. We bring the magnet into position and switch on a field of about 10,000 gauss. We have to wait now for about a minute until the heat of magnetization is carried away. Next we remove the magnet and bring the coils for the temperature measurement into position. The substance has cooled down, the thermometer points to about 0.25°. At the same time you notice that the temperature keeps quite steady.

[4] During the lecture a wire of the thermometer circuit broke, so that the experiment could not be performed. However, it was shown to a large number of the audience three quarters of an hour later when the trouble had been repaired.

We will now make another experiment with the lower substance, B, iron ammonium alum, and the same field. We have now reached 0.1°, and you see that again there is hardly any change of temperature.

Now we will look at Table I, which gives the vapor pressures of helium at different temperatures. Although they have not been measured experimentally, these figures are very accurate, since we have all the necessary data at our disposal

TABLE I

VAPOR PRESSURES OF HELIUM

T°	p (mm)
1.0	1.5×10^{-1}
0.7	3.2×10^{-3}
0.5	2.5×10^{-5}
0.3	7×10^{-10}
0.2	3×10^{-15}
0.1	3×10^{-31}
0.05	4×10^{-62}
0.03	6×10^{-103}

for calculating the vapor pressures according to the second law of thermodynamics. You see that at 0.1° the vapor pressure is 10^{-31}, and at 0.25° it would be about 10^{-12}, so that there is practically no gas which could transmit heat from the surroundings. At 0.5°, however, we have a vapor pressure 10^{-5}, which is no longer negligible. In this case the substance would warm up much more quickly, and so we have the paradox that it is much easier to keep a temperature below, let us say 0.3°, than one above this temperature.[5]

At these very low temperatures one can get any isolation one likes, for instance, at 0.03° we have a vapor pressure of 10^{-102}. The surroundings of the substance are at a temperature of about 1°, where the radiation is certainly negligible, and one can make the suspension so that very little heat is conducted to the substance. Thus we have really no difficulty in keeping temperatures as long as we like, even working with very small amounts of substances.

You saw that using different paramagnetic salts, we reached different final temperatures, which means that all substances are not equally good for this method. Of the many substances we investigated, iron ammonium alum was found the most suitable, and with it we have got down to about 0.04°, using a field of 14,000 gauss. De Haas reached 0.015° with this procedure, using potassium chromium alum, and having the huge magnet of the Leiden Laboratory at his disposal.

I may remind you that the temperature of a material body in the interstellar space can not fall below 2° or 3° K., as it always has to be in equilibrium with the stellar radiation. So you see that in this case we can realize in the laboratory a lower temperature than we can find in nature, and we can surpass the conditions found in nature in still another way. We will look once again at the table of the vapor pressures of helium, the most volatile gas existing. In the interstellar space there is a vacuum of about 10^{-22} cm. Hg. You see that we have already reached this pressure in a space surrounded by a body at a temperature of about 0.15°, even when it is filled with the most volatile gas. At 0.03° the pressure would be so small that in the whole galaxy we would not find one single atom in equilibrium with it. So, in the directions of low density and low temperature, we can surpass in the laboratory the conditions found in nature, whereas, in the opposite direction it is extremely unlikely that we will ever reach the high temperatures and big densities to be found in the stars.

There is not much point in generating low temperatures simply for the fun of

[5] Of course, one could establish a vacuum by means of pumps, but at low temperatures the helium is absorbed in big amounts on the walls, and it would take a very long time to obtain a sufficiently high vacuum.

playing among the low figures. How can one make investigations on substances other than the paramagnetic salts? The most simple way is to press the paramagnetic salt and the substance to be investigated together, so that they form a solid pill. In cooling down the salt, the substance cools with it. In this way we examined a lot of metals to see whether they became supraconducting or not, and three new supraconductors were found in the new region. Some other metals, however, did not become supraconducting down to 0.05°.

At the same time these measurements showed us still another thing. Cooling an additional substance with the paramagnetic salt and seeing how far the temperature is lowered in demagnetizing, compared with the temperature reached in demagnetizing the pure salt, one can measure the specific heat of the additional substance, and see whether anything happens within the new temperature region. If there is any change of energy within the substance that is equal to the thermal agitation in the new region, then it should be seen in these specific heats. And there is a very definite thing that must be expected to happen in this region. As is known from the analysis of the atomic spectra, there is an interaction of the magnetic momenta of the nucleus with that of the electrons, chiefly the valency electron. As a result of this, the ground state of the atom is split up, and the energy difference between the different levels is of such an order of magnitude that the new temperature region is characteristic of it. We have already got some results in this direction, but it would be proceeding too far now to go into details.

You saw that within this new temperature region there really are things that still happen, and it is not only a game with low temperature figures. One can also say that it will be both necessary and interesting to investigate temperatures lower than those yet reached.

What imposed the limit to the temperatures reached above? It should be possible to get down to any temperature if the dipoles in the salt were perfectly free, because then, even as near to absolute zero as one likes, there would be a random distribution of the magnetic dipoles, and we would always still have a means of lowering the temperature. But here the same thing happens as in the case of gases. If we had still a gas at these very low temperatures, we could certainly use it for lowering the temperature, but no more gas exists, because there are forces between the atoms that cause the system to pass over to a state of order—the crystal—and there is no longer any disorder that we could make use of for lowering the temperature. In the paramagnetic salt the same thing happens, only at temperatures about 100 times lower. In them there also exists interaction forces which have the effect of establishing an order within the system without an external magnetic field, and so at these temperatures the paramagnetic salts cease to be of use. These temperatures differ, of course, from substance to substance, and we saw in our experiments that the manganese ammonium sulfate passed over into this state earlier than the iron ammonium alum. Of course, one could get a bit further by using still stronger magnets, but I think the practicable limit has been reached with the dimensions of the Leiden magnet.

A more hopeful way seems to be to work in two stages. That means, first work down to about 0.05°, and then starting at this temperature go still lower with a new procedure, like the cascade for liquefying gases, which was used so much in the past. Of course, to get to appreciably lower temperatures for the lower stage it will be necessary to find a

substance in which these interaction forces, which tend to bring the system into an ordered state, are still smaller than within the substances hitherto used. I have already said that the interaction forces between the nuclear moments and their surroundings are very small, and in the second stage one will have to try to work with a substance that exhibits nuclear paramagnetism.

But even here there are some interaction forces, and so this will only work for a bit of the way to absolute zero. And with all other phenomena that may still happen in the new temperature region, it will certainly be the same. There exists a law, Nernst's Theorem, also called the third law of thermodynamics, which is confirmed by all experiments. It postulates that at absolute zero all substances are in a state of perfect order, or in other words, that the state of lowest energy must be a state of perfect order. And we know now that this means that it will be impossible ever to reach the zero of temperature absolutely. But this does not mean that one can not get below a certain limit, say 1/10,000°. It will be possible to reach any finite temperature, be it as small as you like. But the technique of reaching such a temperature will always be dependent on finding a phenomenon, connected with only a very small energy change, happening within a system. And so you see that this last degree, or as we may say now, the last 1/100° to absolute zero, though absolutely very small, stretches in reality an infinite distance before us. And this infinity is not an empty one, but one that is filled with phenomena worth investigating.

SCIENCE AND MILITARY TECHNIQUE

By ROBERT K. MERTON

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The subjects investigated by science are determined by social, as well as purely scientific, factors.—Military technology has focussed scientific attention upon certain groups of problems.—About ten per cent. of the research conducted by members of the Royal Society in seventeenth-century England was so influenced.

THE foci of scientific interest are determined by social forces as well as by the immanent logic of science. It is only by examining extra-scientific influences that one can fully comprehend the reasons why scientists have applied themselves to one field of investigation rather than to another. For science is a social outgrowth and the direction of scientific research is largely induced by social factors. With the view of tracing such a connection between science and society, I shall indicate the ways in which military exigencies have encouraged the growth of one branch of science, especially in seventeenth-century England.[1]

The seventeenth century in England was one in which war and revolution were rife. Moreover, the dominance of firearms (both muskets and artillery) over side-arms first became marked at this time—swords and pike disappeared almost completely as weapons of importance (except as they were incorporated in the removable bayonet about 1680). Especially notable was the enhanced use of heavy artillery, for in this field occurred a change of scale which raised new technical problems. Ever since the early fourteenth century, cannon, or "firepots," had been used in warfare, but it was not until three centuries later that they played an important rôle in military technique.

[1] Compare the paper by B. Hessen in "Science at the Cross Roads," pp. 151–212. London, 1932.

Leonardo was one of the first to combine military engineering and scientific prowess, as is evidenced by his polygonal fortress, steam cannon, breech-loading cannon, rifled firearms and wheel-lock pistol. Other scientists likewise employed themselves with such matters. Niccolo Tartaglia, in his "Nuova scienza" (1537), dealt with the theory and practice of gunnery. Georg Hartmann invented a scale of calibers which provided a standard for the production of guns and furthered the empirical laws of firing. Galilei, in his "Dialoghi," suggested that (ignoring air resistance) the trajectory of a projectile described a parabola; while Torricelli concerned himself in great detail with the problems of the trajectory, range and fire zone of projectiles. Leibniz, as is evidenced by his posthumously discovered writings, was greatly concerned with various aspects of military problems, such as "military medicine," "military mathematics" and "military mechanics." He also worked on a "new air-pressure gun," as did Otto von Guericke and Denis Papin. Isaac Newton, in his "Principia" (Bk. II, sect. i–iv) attempted to calculate the effect of air-resistance upon the trajectory of a projectile. Johann Bernoulli, who also studied the expansion of gunpowder gases, pointed out Newton's error, with the result that it (Bk. II, Prop. 37) was eliminated in the second edition of the "Principia." Euler continued the theory that the parabola best approximates the actual trajectory of a projectile; a subject dealt with minutely by Maupertuis.

But all this simply indicates that out-

standing scientists have at times been directly concerned with matters of military technique. In order to see the ways in which such practical exigencies aroused research in certain fields of "pure" science, it is necessary to make a detailed study of another sort.

The technical and scientific problems set by the development of artillery in the seventeenth century were briefly these. Interior ballistics is concerned with the formation, temperature and volume of the gases into which the powder charge is converted by combustion, and the work performed by the expansion of these gases upon the gun, carriage and projectile. Formulae for the velocity imparted to a projectile by the gases of given weights of gunpowder and for their reaction upon the gun and carriage must be computed to determine the correct relation of the weight of charge to the projectile's weight and length of bore, the velocity of recoil, and the like.

Not only were such nineteenth century scientists as Gay-Lussac, Chevreul, Graham, Piobert, Cavalli, Mayevski, Otto, Neumann, Noble and Abel concerned with these problems, but also many earlier investigators. Of obvious fundamental importance for interior ballistics is the relation between pressure and volume of gases. That the volume of any gas varies inversely as its pressure was first stated by Boyle in 1662 and verified independently by Mariotte some fourteen years later. Apparently Boyle was not unaware of the relation between his discovery and problems of interior ballistics, for he proposed to the Royal Society "that it might be examined what is really the expansion of gunpowder, when fired."[2] This same problem was investigated in detail by Leeuwenhoek, who, although he resided in Holland, may be considered in the stream of "English science," by virtue of the 375 papers which he sent to the Royal Society, of which he was a member. His experiments in interior ballistics, published in the *Transactions*, aroused sufficient interest to be repeated before the society by Papin.

At one of the early meetings of the society, both Boyle and Lord Brouncker, the latter of whom was especially interested in ballistics, suggested experiments on air-pressure and the expansion of gases. One of the proposed experiments dealt with the inflammation and combustion of a charge of powder—a problem basic to the noted memoirs in interior ballistics by Noble and Abel, read before the Royal Society in 1874 and 1879, respectively.

At one of the earliest meetings of the society "the lord viscount Brouncker was desired to prosecute the experiment of the recoiling of guns, and to bring it in at the next meeting."[3] These experiments were frequently repeated and followed with great interest by the other members of the society.

Exterior ballistics is concerned with the motion of a projectile after it leaves the gun: it treats of the trajectory and the relation between the velocity of a projectile and the resistance of the air. The most notable experiments in exterior ballistics in the last two centuries were those by Robins, Hutton, Didion, Poisson, Helie, Bashforth, Mayevski and Siacci, but these were in turn largely based upon scientific work of the preceding period.

The fact that Galilei introduced his "Discorsi," in which he dealt with the trajectory of a projectile, with an acknowledgment of the assistance rendered him by the Florentine arsenal suggests that he was aware of his work for ballistics. Moreover, as Whewell noted, the practical military applications of the

[2] Thomas Birch, "The History of the Royal Society of London," I, p. 455, 4 vols. London, 1756.

[3] Birch, *op. cit.*, I, p. 8.

doctrine of projectiles doubtlessly helped to establish the truth of Galilei's views.

The study of the free fall of bodies—so essential to exterior ballistics in its initial stages—was continued by Robert Hooke in his experiments with the fall of "steel" bullets. He followed this investigation with some experiments designed to determine the resistance of air to projectiles. This resistance, he maintained, could be tested by "shooting horizontally from the top of some high tree." Hooke went further and constructed an engine "for determining the force of gunpowder by weight"—an experiment which proved of sufficient interest to be repeated at two subsequent meetings of the society.

Christopher Wren, concerned with the invention of "offensive and defensive engines," was, with Wallis and Huygens, the first to state correctly the motion of bodies in their direct impact. This law, together with the first two laws of motion, affords a basis for an approximation to the trajectory of a projectile.[4] Roger Cotes, Newton's disciple who redacted the second edition of the "Principia," similarly occupied himself in his "Harmonia Mensuarum" with the motion of projectiles.

The problem of the trajectory was attacked by Halley, who demonstrated the utility of Newton's analysis in the "Principia" for this purpose. Cognizant of the economic, as well as technical, advantages to be derived from his mathematico-mechanical formulation of the approximate trajectory of projects, Halley indicated that his "rule may be of good use to all Bombardiers and Gunners, not only that they may use no more Powder than is necessary to cast their Bombs into the place assigned, but that they may shoot with much more certainty."[5]

[4] See the "Principia," "Scholium to Laws of Motion."

[5] *Philosophical Transactions*, 16: 3–20, 1686.

Sir Robert Moray introduced to the society Prince Rupert's gunpowder, "in strength far exceeding the best English powder," as well as a new gun invented by the prince. Moray likewise suggested a series of experiments in gunnery, which were broadcast in the *Transactions*. These trials aimed to determine the relation between the quantity of powder, caliber of gun and the carrying distance of the shot. Similar experiments were conducted by the sometime Savilian professor of astronomy, John Greaves.

It appears evident that contemporary scientists were interested in problems and investigations which pertained directly to military technology, but, what is perhaps less apparent and more significant, many researches devoted to "pure science" were also related to such problems. For example, the study of the free fall of bodies, which since Galilei occupied such a prominent place in physical research, is necessary, if the trajectory and velocity of a projectile is to be determined. The connection between these problems was made explicit when an experiment was frequently performed before the Royal Society "for finding the velocity of a bullet by means of the instrument for measuring the time of falling bodies."[6]

In an effort to determine the approximate extent to which military techniques and problems have tended to focus the attention of scientists upon certain problems, I have computed the comparative number of inquiries and experiments carried on by the Royal Society which are related, directly and indirectly, to such military needs. By tabulating the number of experiments listed in the minutes of the society during four years in the later seventeenth century and classifying them in terms of the fields to which they pertained, it is possible to secure an approximate comparison of

[6] Birch, *op. cit.* I, pp. 461, 474, *passim.*

this kind. Each experiment or inquiry listed in the society's minutes (as published in Birch's History) is counted as one "unit" and classified in the field to which it is most closely allied. The field of military technology was classified in the following fashion.

MILITARY TECHNOLOGY

A. *Directly related research:*
   (1) Study of trajectory and velocity of projectiles.
   (2) Processes of casting and improvement of arms.
   (3) Studies of the relation of the length of gun-barrels to the range of bullets.
   (4) Study of the recoil of guns.
   (5) Experiments with gun-powder.

B. *Indirectly related research:*
   (1) Compression and expansion of gases: relations between volume and pressure in the gun.
   (2) Strength, durability and elasticity of metals: elastic strength of guns.
   (3) Free fall of a body and conjunction of its progressive movement with its free fall: determination of the trajectory of projectiles.
   (4) Movement of bodies through a resistant medium: enables a closer approximation to the trajectory of projectiles as influenced by air resistance.

In the year 1661, the Royal Society pursued 191 separate scientific investigations. Of these, 18 (15 directly related, 3 indirectly related) or 9.4 per cent. were related to military technology. In 1662, of 203 projects, 23 (4 direct, 19 indirect) or 11.3 per cent.; in 1686, of 241 projects, 32 (22 direct, 10 indirect) or 13.3 per cent.; and in 1687, of 171 projects, 14 (8 direct, 6 indirect) or 8.2 per cent. Thus we see that on the average about 10 per cent. of the research carried on by the foremost scientific body in seventeenth-century England was devoted to some aspect of military technique. To an appreciable extent, then, this one extra-scientific factor tended to focus scientific attention upon a given body of scientific problems.

The relations between military demands and the scientific development of the time were primarily of two sorts. The first involved conscious, deliberate efforts of the contemporary scientists directly to solve problems of military technology. This is what is meant by a *direct* relation. The second type is less apparent, for it concerns scientific devotion to problems which, although either imposed or emphasized by military needs, seemed to the scientists as primarily of purely scientific interest. This was called the *indirect* or derivative relation. Concern with the expansion of gases, combustibility of powder and the consequent pressure of the products of combustion, and the durability and resistance of materials may in individual instances involve no consciously felt connection with military technology, although the original impetus for such study may have been considerably enhanced through military requirements. These derivative problems may enter into scientific tradition as problems of purely scientific interest, and yet may have been originally introduced for practical reasons. This is to say that many scientific researches proceed along lines largely independent of social forces once the initial problems have become evident, and in this way, research may progress which is related only in a tenuous and hardly appreciable fashion to military or economic developments. Thus science develops a corpus of investigation which has its origin in strictly scientific, and not grossly utilitarian, considerations. It is these developments (which probably constitute the greater part of science) arising from the relative autonomy of scientific work that seem to have little or no connection with social forces.

A THEATER OF THE SCIENCES

By Dr. IRA M. FREEMAN

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THE steadily increasing interest in scientific matters on the part of the general public is one of the most remarkable social and cultural phenomena of recent years. The wide-eyed wonder at the "mysteries and marvels of science," which was the characteristic reaction of the public a quarter of a century ago, is being replaced by a sober inquisitiveness and serious interest; and thinking individuals are demanding that their curiosity regarding scientific matters be satisfied in a legitimate manner.

It is true that attempts are being made to meet this need. There are press associations and individual newspapers conveying trustworthy and accurate scientific information to their subscribers, but neither scientific journalists nor journalistic scientists have been able to reach any degree of unanimity on methods of presentation,[1] and—with the exception of a small number of reputable writers and press associations—the field is still in the hands of charlatans who, in their innocence, believe the average person to be like the simple hero of one of George Ade's stories who "was kicked in the head by a mule when very young and believed everything he read in the Sunday papers." Perhaps the generally prevalent underestimation of the public intelligence is responsible for our failure here as well as in connection with another potentially promising yet virtually unexplored cultural medium—the motion picture.

It might be urged that it is the duty of the schools to satisfy this want, but obvious difficulties exist: In the first place, a large number of the population can not take advantage of formal instruction because they do not have sufficient preparation, adequate time or the required funds. The survey courses in science which are finding their place in the curricula of more and more institutions of higher learning serve an admirable purpose in interpreting the spirit of scientific endeavor to college students who have had no previous scientific training, but they are at once unavailable to the great body of people who can not attend college.

Moreover, the hypothetical intelligent layman does not ask for *systematic* instruction. He wants, more often, immediate and intelligible answers to particular questions which arise in his mind, usually through some everyday contact; and he insists that his information be vividly, simply and interestingly presented. Frequently he desires, too, an inkling of how science and scientists "get that way," *i.e.*, some idea of the spirit, methods and scope of science. The remaining part of the complete account—the story of the systematic structure of science and its orderly array of supporting facts—is something which must be administered deftly and unobtrusively, if at all.

It must be realized, of course, that we can not make of every layman a trained scientific investigator (nor would this be a very interesting world if we could!), but we can direct interest in science to gratifying ends. We need but recognize the fact that, besides having intrinsic "practical" worth, science can be looked upon as a cultural pursuit, deserving of a place alongside music, the

[1] See, for example, the letters by two of our leading scientific journalists in *Science*, June 14, 1935 (p. 591), and in the same journal for June 28, 1935 (p. 640).

drama, art, literature, etc., in the life of the individual—as a hobby, which it often was in its earlier history—quite apart from any professional or technical applications it may have. Indeed, according to Pearson,[2] "there is an insatiable desire in the human breast to resume in some short formula, some brief statement, the facts of human experience. . . . It leads civilized man . . . to express his emotional experience in works of art, and his physical and mental experience in the formulae or so-called laws of science. Both works of art and laws of science are the product of the creative imagination, both afford material for the gratification of the aesthetic judgment."

If, then, we face the fact that interest in science on the part of the people is beginning to manifest a sort of restless germination, and if we realize that neither the press nor the school is at present able to foster that interest adequately, how is the situation to be met? In order to answer this question, let us examine the means by which some other attributes of a cultural life are garnered. A love and appreciation of good music is, of course, fostered by hearing competent and artistic renditions of musical compositions; interest in art is developed and quickened by viewing actual works of art; the spirit of the drama is to be sought in representative plays interpreted by talented actors. Often we must be content with substitutes for these stimulating first-hand contacts: We listen to phonographic or radio renditions of music in place of enjoying the sparkling animation which only the concert hall can offer. Compare the satisfaction of perusing a pedantic treatise on the drama with witnessing an absorbing play well acted. Contrast the reading of a printed essay with listening to an eloquent, arresting speaker!

[2] Karl Pearson, "The Grammar of Science," Pt. I, p. 36, The Macmillan Company, 1911.

From all of this we may understand that the direct and vivid method of interpretation exemplified by the theater, the concert hall and the opera house—involving a simultaneous, coordinated appeal to both the visual and auditory senses—might prove the most effective means of presenting scientific material. By a long process of evolution, the theater has developed a spirit and method of portrayal which is basically well founded and effective. The psychology of the theater is essentially sound; the auditors come to be entertained—they are at once in a receptive mood. The physical devices of the ideal modern playhouse sustain and enhance this spirit; the skilful blending of form, color and music into a harmonious whole, the fusion of many arts to produce a pleasing effect—all these contribute to the success of the offering, whether its purpose be casual diversion or the transmission of an earnest message.

In order to adapt both the spirit and the physical equipment of the drama to the presentation of scientific information, it is proposed that a Theater of Science be established—a theater where, by means of extensive demonstrations, the chief rôles are played by natural phenomena and where the laws of nature may be seen in intimate "personal appearance."[3] Otherwise expressed, the science theater would stand in the same relation to all science and technology as the planetarium does to astronomy.

In a large city or center of population, a building would be erected to house the auditorium, preparation rooms, apparatus storehouse, shops, library, conference rooms and offices. The theater audi-

[3] While these views are here expressed in the language of the theater, this type of presentation is not to be confused with dramatic offerings or motion picture plays based upon episodes in the lives of great scientists, although such have often been suggested and some examples have actually appeared. Consult Benjamin C. Gruenberg, "Science and the Public Mind," pp. 127–8, The McGraw-Hill Book Company, 1935.

torium must have upon its stage highly adaptable lecture and demonstration tables fully equipped with those features found in modern university science lecture halls and with certain others made necessary by the peculiar requirements of the present endeavor. Running water, compressed air, compressed oxygen, illuminating gas and electric current at various voltages and frequencies should be available.

The apparatus used in conjunction with demonstration lectures is to be assembled in preparation rooms flanking the lecture platform. If lectures are to follow one another at rather short intervals—and this is almost a necessity if building and equipment are to be utilized to best advantage—a revolving stage would be highly desirable, so that one lecture might be set up on the rear section of the stage while another is in progress on the side facing the auditorium. Revolving stage installations in several American and European playhouses are operating with success and contribute effectively to the enjoyment of the performance by shortening *entr'actes* and by permitting of novel effects otherwise impossible.[4] Air conditioning of the auditorium would not only contribute to the comfort of the audience but would be of decided value with respect to the successful operation of the demonstrations, *e.g.*, humidity control for electrostatic experiments.

Visual aids are, of course, of utmost importance here and must be available in every required form. Provision should be made for the effective display of charts and graphs, and there must be complete projection equipment for standard sound motion pictures[5] and for slides. A useful addition to the projection lantern is an attachment for opaque projection of geological specimens, etc. A microprojector is indispensable, especially in conjunction with lectures in biology.

Demonstration apparatus for use in the science theater must be selected with great care and with regard for simplicity. The present tendency appears to be to make a piece of apparatus bristle with vacuum tubes and photocells, but these highly sophisticated impedimenta serve only to obscure the basic simplicity of the phenomena to be shown. Besides being severely simple, the apparatus should be designed in a way which makes it easily visible to a large audience. Apparatus built for ordinary laboratory use may be inadequate in certain instances, requiring special constructions of "heroic" size.

Far more important to the success of this venture than plant and equipment is the type of lecture offered in the Theater of Science. The cardinal principle is the fact that the lectures are for the benefit of the layman and not for the trained scientist—indeed, in no case must any previous special knowledge, training or background be presupposed. In the words of the late Edwin E. Slosson, the first director of Science Service,[6] the expositor must "weave in" the background as he goes along. The lectures must always be entertaining and of human interest and—in a legitimate sense—spectacular. Their aim must be to convey something of the spirit and methods of science rather than a mass of detailed information. The presentations should be

[4] See, for example, Irving Pichel, "Modern Theatres," New York: Harcourt Brace and Company, 1925.

[5] These may be used in connection with certain lectures where suitable film subjects are at hand. A reasonably complete selection of such films does not yet exist. For more advanced auditors, however, subjects such as those made cooperatively by The University of Chicago and the Erpi Pictures Consultants of New York are obtainable. See H. B. Lemon in *Journal of the Society of Motion Picture Engineers*, pp. 62–67, January, 1934.

[6] A highly reputable press service, with headquarters in Washington, D. C., supplying accurate science news to many of the country's leading newspapers, and publishing the weekly *Science News Letter*.

accurate, definite and informative, but not necessarily systematic. Any actual instruction which the audience receives will be obtained in the guise of entertainment. The publicity material should stress this point by billing the lectures as "entertainments," and auditors should be left to discover for themselves the substantial content and value of the lectures without being continually reminded that they are to be "uplifted" or "inspired." To label these lectures explicitly "cultural" would be fatal. Millions who viewed the excellent science exhibits at the recent Century of Progress Exposition in Chicago found them absorbingly interesting and came away feeling that they had had a good time. They were not stampeded into attending, and science, on its own merits—competed successfully with the great variety of other "entertainment" offered at the exposition.

The regular lectures are intended to appeal to the average adult. However, it may be desirable to offer afternoon lectures for juvenile audiences as well.[7] School children of to-day exhibit an eager inquisitiveness regarding science and technology, and it is fully as important to nurture and develop their interest in this instant as it is to awaken and to guide interest in art, music and literature in early childhood.

To those whose curiosity regarding particular topics is sufficiently aroused, bibliographies of graded reading and study might be supplied. Works to which reference is made would be available in the library of the building.

The initial costs of this undertaking might be met by funds contributed by the local, state or national governments, by popular subscription, by individual donors, or by a combination of these sources. In all likelihood, operating costs could be met adequately by charging a small admission fee. A plan involving course tickets at a reduced rate and life memberships, including a subscription to a reputable popular science periodical, also suggests itself.

It is entirely feasible for any city of sufficient size to have a Theater of Science—a source of wholesome entertainment and diversion, a refuge from the strife and bickering of a chaotic world, a fountainhead of inspiration where, in time of trouble, one may take comfort in the immutability and steadfast permanence of eon-old natural laws, a means of turning from vexing thoughts and laborious mundane pursuits to something which occupies the mind, stirs the imagination and inspires courage for the future.

[7] Similar, for example, to the famous Christmas Lectures at the Royal Institution in London.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE DEPRESSION AND MENTAL DISEASE

By Dr. CARNEY LANDIS

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ALMOST every one is certain that he understands himself very well and the actions and conversation of most other people fairly well. But when we and our friends fail to understand the actions of a man we usually call that not-understood man crazy. In other words, we say a person is suffering from mental disease when his behavior and conversation seem to us illogical, irrational or inappropriate. We are frequently unable to reason with this man in the terms of everyday common sense. Most often the person himself does not realize his condition, but if he does, he usually says that somehow he has lost control of his thoughts or actions. A word of caution should be made here, namely, that we do not regard as diseases the minor eccentricities of everyday life, such as individual oddness, hysterics, temper tantrums or similar peculiarities. These ordinary exhibitions of temporary unreasonableness, although similar to the behavior of the insane, are after all either temporary or they do not seriously interfere with a man's everyday life.

Since the person we call insane can not tell us why he acts as he does and since in most cases we find no physical trouble which might be responsible for the behavior, we have been in the habit of thinking that insanity is caused by circumstances such as grief, disappointment, unrequited love, loss of employment or savings, physical injury or by general mental stress. Any or all of these may have happened before the disease began; hence it is easy to say they are the reason for the insanity. Because of things the patient may have said, the way in which he behaves or the kind of person he was before he became sick they are easily accepted as reasons. They are all circumstances which every one can understand and which in the absence of any evidence to the contrary are considered acceptable explanations.

Essentially then, common sense holds that undue, prolonged mental stress leads to insanity. Most unwillingly and unwittingly we have been going through a practical test of this popular theory. We are slowly emerging from a severe economic depression and are still in the midst of a social revolution. The increased unemployment, the wage reductions, the loss of savings, together with the sense of social and economic insecurity of the past six years have brought an ever present mental stress, a feeling of insecurity and of tense unhappiness. Certainly in the face of this stress the number of persons suffering from mental disease must have sharply increased, if the common-sense explanation is correct.

The social and economic importance of this problem is further emphasized when one remembers that for several years past almost half of the hospital beds in the United States have been occupied by patients suffering from nervous and mental diseases. Since most of these patients have no means of self-support, this burden represents one of the large items in American governmental budgets.

Fortunately, accurate and adequate statistical reports of occurrence of mental disease have been published annually

for the past twenty-two years by the state of New York. These New York State figures are representative and typical of the condition as it has existed in every one of the states. A first examination of these reports shows that 6,300 new cases were admitted to all the New York State mental hospitals in 1912, while about 12,000 cases were admitted in 1934. This is an apparent increase of 87 per cent. But we must remember that the general population has also increased between these years. If we allow for this general population increase by basing our figures on the number of cases per 100,000 population, then we find that the rate was 67 in 1912 and 86 in 1934, an increase of 27 per cent. This is for all mental hospitals in the state of New York, both private and state, and includes all cases, regardless of diagnosis, admitted to mental hospitals for the first time.

At first thought many have been inclined to attribute this increase of 27 per cent. in mental disease to the increase in the complexity and tension of present-day life. However, when we examine the figures more carefully and separately study each variety of mental disease, we find, much to our surprise, that for all kinds of mental diseases, save one, the number of cases per 100,000 has remained remarkably constant for the past 22 years. This one disease that has increased in prevalence is known as cerebro-arteriosclerosis. It is a condition brought about by hardening of the blood vessels of the brain occurring almost entirely in people over 45 years of age. The rate for patients sent to mental hospitals on account of this disease has increased from less than 2 per 100,000 in 1912 to over 14 per 100,000 in 1934, an increase of almost 700 per cent. in 22 years. I am inclined to think that this tremendous increase is mostly, though not entirely, due to the fact that during the past quarter century there has been a gradual and consistent increase in the per cent. of total population who are old enough to develop cerebro-arteriosclerosis. In 1912, for example, less than 21 per cent. of the New York State population were over 45 years of age. In 1934 this figure had increased to almost 25 per cent. In brief, individuals 45 years of age or over accounted for one fifth of the general population in 1912 and for one fourth of the population in 1934.

This increase in the number of people over 45 is mainly due to public health work and preventive medicine, which has added more than 10 years to the life span of the average American citizen since 1900. Many people who 50 years ago would have died of appendicitis, typhoid, diphtheria, or the like, during their twenties or thirties, are now living to reach the age when they are susceptible to arteriosclerosis.

If we make a fair allowance for the arteriosclerotic and senile cases now being admitted to our hospitals, we find that the apparent increase of 27 per cent. in mental diseases during the past 22 years has dropped to an apparent increase of about 8 per cent.

It is highly questionable whether even this slight increase of 8 per cent. of hospital admissions is a true increase of frequency of occurrence. Certainly we must allow for the increased number of people who live in cities and for the continued development of more adequate hospital facilities. With respect to the first factor, it has long been pointed out that the number of hospital cases for most of both physical and mental diseases is considerably higher for the city than for the country. In general, the number of urban mental hospital cases exceeds the rural at a ratio of 3 to 2. In part this is due to such things as the greater utilization of hospitals and clinics by city dwellers or to the greater difficulty of caring for the mentally ill in a city apartment. Undoubtedly the apparent increase of 8 per cent. in mental disease is partly due to the fact that in 1934 the cities of New York State ac-

counted for 84 per cent. of the total population, as compared with less than 80 per cent. in 1912.

There remains to be considered the factor of available hospital facilities. In 1912 there were in New York State about 370 beds available per 100,000 population for mental disease patients, while in 1934 there were over 600, an increase of about 64 per cent. Since obviously the mental hospital population is partly dependent on the available hospital facilities, the large increase in number of hospital beds has contributed to the slight apparent increase in mental disease rate.

If we again return to the statistical reports and compare the rates for 1928, a year of prosperity, with 1932, a year of marked economic depression, we find that the rate of admissions to mental hospitals is practically the same, namely, 68.7 and 68.3 per 100,000 population when cerebro-arteriosclerosis is omitted from the computations. If we compare 1913, a year of peace and relative prosperity, with 1918, when the stress of the great war was at its height, we find that the corrected rates are identical, namely, 68 per 100,000 population.

In general, then, if we allow for the increased age of the general population, urban-rural rates and hospital facilities available, we find that we have a very constant rate of hospitalized mental disease which apparently is not affected by economic depression and its accompanying mental stress. I repeat, depression, financial insecurity, unemployment and general unrest have not led to any increase in hospitalized insanity. This does not mean that there has not been plenty of mental stress and anguish, plenty of ragged nerves and unhappiness, but these psychological stresses and tensions have not led to an increased rate of hospitalized mental disease.

If mental stress does not lead to mental disease, then why mental disease? It seems to me that from the evidence I have given, taken together with a vast amount of other relevant material, the conclusion is obvious that in spite of the mental symptoms, in spite of what the patient says, in spite of what relatives and friends say and in spite of the usual belief, the basis of mental disease is not to be found in the psychological stresses of economic depression or social unrest. The essential basis for the increased number of hospitalized mental patients is a population problem. Such factors as the increase in the general population, in the average age of our citizens and in the increased hospital facilities account for our present situation.

This does not mean that the mental side of the disease picture is unimportant. It is important that the patient suffering from any disease be kept in good spirits and as calm as possible. It is interesting, necessary and often vital to know and understand the mental life of the patient, but it seems to me that the study of mental life can only indirectly lead us to a sound understanding of the essential basis of the disease. For instance, we can tell from the behavior and mental processes of a man whether he has been drugged by morphine or alcohol. A skilled physician can frequently differentiate various physical diseases on the basis of the behavior and conversation of the patient, even when the illness is not mentioned. So the study of the psychological life of the patient may lead on to a better understanding of underlying constitutional factors which must be the essential basis of mental disease.

To sum up, insanity is popularly supposed to follow or to be the result of a generally increased mental stress and tension. This is not so! An examination of the records shows that although we have gone through a great war and three economic crises during the past 22 years, the rate of mental disease, when corrected for factors known to directly

affect it, has held remarkably constant with the exception of those diseases associated with old age. This increase in old age diseases we have attributed to the fact that after all a man must die of something and if typhoid does not take him at 30, cerebro-arteriosclerosis may at 60. The depression of itself has not led to any real increase in mental disease, in spite of the fact that it has undoubtedly increased mental stress and unhappiness.

WHY WE NEED WILD BIRDS AND MAMMALS

By Dr. J. GRINNELL

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THERE is an old maxim to the effect that "familiarity breeds contempt." In my mind, nothing more clearly illustrates the truth of this statement than man's varying attitude toward nature. There was a time when human beings knew so little of nature that they invested everything about them with a mysterious, even spiritual significance, and frequently did not dare to kill certain living things for fear that nature would visit vengeance upon them. In recent centuries, however, man has become more familiar with the workings of nature, and at the same time, seemingly in consequence of this familiarity, well-nigh contemptuous. Where primitive men avoided conflicts with nature because of ignorance and superstition, modern men sometimes go out of their way to fight nature, because they have learned enough to drop superstition but have not yet acquired anywhere nearly complete understanding, such as should bring respect for her complicated and, on the whole, beneficent ways.

It is because of this disrespect that vast forests have been destroyed, and that hillsides and valleys have been unwisely denuded of their natural cover. It is because of this attitude, too, that many types of animals have become extinct, or are approaching extinction—certain of our most prized kinds of fur-bearing animals, several kinds of wild ducks and geese, the passenger pigeon and the great California condor.

Too often have human beings suffered by reason of their ignorance of the scheme of nature. Blinded by immediate expediencies we have failed to foresee the effects of destructive operations against nature. Immediate profit has seemed more important than future welfare. Temporarily practical considerations are given right-of-way over permanent cultural benefits. All this, because we fail to perceive the whole of what nature provides.

It would be foolish to propose, of course, that nature should be allowed to remain absolutely undisturbed. For in our own presence anywhere we impinge upon natural conditions. But it is only common sense to urge that such disturbances as are really necessary be undertaken only with as complete an understanding of the situation as possible, and hence only as following upon studious observations of the most comprehensive sort. When crop protection makes local action against certain rodents advisable, it should not be forgotten that burrowing animals on uncultivated lands perform an important function in developing and maintaining the soil. Every effort should be made to limit destruction to a minimum, for wildlife is an asset to us not only from the obviously practical view-points of the farmer, the sportsman

and the water conservationist, but from those more subtle aspects apparent to the vacation-seeker and the nature-lover.

With each passing year we reach a clearer understanding of the complexity of nature. Through the patient work of field biologists and nature students, new factors in the relationship between wildlife and human affairs are constantly coming to light. As an example of what I mean I am going to tell you of an experience I recently had.

The second week of last October found me in the Sierra Nevada of California, walking along the main road which leads up the mountainside into Sequoia National Park. As the morning sunshine began to increase the warmth and dryness of the atmosphere, I noted the sound of falling and bouncing acorns of the black oaks which were just then yielding their annual crop. The slope was steep; and along about ten o'clock the sound and sight of descending acorns was impressive. They were even accumulating in little windrows along the inside of the road next to the bank; and now and then, one from far up-slope, having gained extra momentum, bounced clear over the road and proceeded on its way toward the canyon bottom below.

Acorns are smooth-shelled, heavy objects, and those of the black oak in particular are of rotund shape. These qualities make them insecure on any slope upon which they fall, until in their movements they reach some crevice or sufficiently wide strip of level ground on which to find lodgment.

It was clear to me that the direction of seed scattering from any one oak tree was well-nigh directly down-hill. In that place and on that day I saw *no* acorn moving *up*-hill. Gravity alone acted as the agency of distribution. There appeared no possibility of wind as an agent of elevation, as with seeds of such trees as maple, cottonwood and willow. In the case of the oaks, it might therefore seem, the only possible direction of general forest spreading through time would have to be, through the action of gravity and streams of water, always down-hill. But how, then, could forests ever have spread, naturally, so as to gain altitude on our many mountainsides?

The next two days, I spent a little to the westward, at about 1,000 feet altitude, in the valley of the lower Kaweah River, where another kind of oak, the blue-oak, abounded. Here I became aware of the presence and especially of the activity of certain birds, the jays. This activity, when looked into, became of deep significance; for here was the agency, at this particular place at this particular time, of transportation of acorns up-hill. The jays centered their interest in those most abundantly fruiting trees down in the bottom of the canyon. There, from morning to evening, they were gathering the acorns and carrying them up the slopes, to be ensconced in various hidey-holes, some of them to be buried, after the well-known blue-jay tradition, in the ground on the hillsides.

Every bird going up-slope bore an acorn lengthwise in its bill; every bird in return course was empty-billed. If I had only thought of it, here was a chance for counting birds, and their loads, in sight, during say, a three-hour period; and then computing the bushels of blue-oak acorns being elevated by the birds perhaps hundreds of feet each October day in that one valley.

In this same locality I saw ground squirrels busily gathering acorns that had fallen to the ground, carrying them in various directions to their burrows or to their shelling stations. Twice I watched a ground squirrel climb up a blue oak to the larder of a group of California woodpeckers, filling its cheek pouches with the acorns they had gathered and stored, even though being attacked by the resentful birds. Then the squirrel would go precipitately down the trunk and off to its own cache in the ground.

Observations of the kind just cited, gathered into notebook and memory, from many parts of the West, have convinced me that certain birds and mammals constitute a paramount agency in the dispersal of oaks and many other trees and shrubs. My recollections bring into this credit column not only California jays, woodpeckers and ground squirrels, but also gray squirrels, red squirrels, chipmunks and wood rats, and Steller jays and band-tailed pigeons. In reflecting upon this matter, we can readily see that the relationship is of reciprocal benefit; for all these animal agents of seed dispersal are supplied by the oaks with food or shelter or nursery sites. The trees produce crops of nutritious seeds—each seed nutritious either to the prospective oaklet or to the animal that eats it—in vast excess of immediate seeding needs. There is enormous seeming extravagance on the part of the trees, far greater production of seeds than would be needed to provide for persistence of the species, if the species were of fixed geographic position through time. The point I wish to make is that in the long-time interests of the tree species, involving migration of the whole forest, there is value-received from this seeming over-production of acorns. It is not extravagance, but good investment.

At any time, catastrophe may overtake the fortunes of the oak forest. Fire may destroy all the growths on a given slope clear to the top of the ridge. Then quick recovery—early repopulation by the oaks—will likely be dependent upon the survival and germination of acorns previously buried by animals in open places, where the heat was least effective, as also upon the year-by-year marginal replanting processes just described. I think especially of California's great erosion-guarding and water-conserving chaparral belt, of which the live oaks and scrub oaks of several kinds are prominent constituents—and their constant animal attendants, the California jays and the dusky-footed wood rats.

There are many kinds of oaks in California, each largely limited to some favorable climatic or topographic situation. The result is that the different species of oak occur in rather sharply delimited belts. It is this fact that lends added importance to the seed-distributing activity of birds and mammals. For we know that during past millenniums the local climatic and topographic conditions have shifted time and time again through the gradual elevation or depression of the land. This means that tree species have had to move their habitat from one period to the next or die in a struggle against oncoming adverse conditions.

Allowing our imaginations free rein, can we not visualize entire forests slowly marching up-hill or down-hill or to one or another point of the compass? Of course, oaks do not literally uproot themselves and move bag and baggage. Some of them may live 300 years in one spot. But as the older trees die out, the exigencies of the environment determine where new trees will sprout and mature and may lead to a shifting of the entire belt. In the pageant of natural history, trees often have been forced, in this sense, to shift their positions or become extinct. Their ability to do this has depended upon the availability of some means of distributing seeds in the direction of a more favorable environment.

Here, then, is where a certain portion of the associated animal life has come into the service of the oak species. In the present era, with life-zones probably advancing northward, and up-slope, we can think of the successive belts of valley oaks, blue oaks, golden oaks, black oaks and huckleberry oaks, on our mountainsides, as relying most especially for that part of their dispersal involving elevation entirely upon their bird and mam-

mal associates. The same sort of relation doubtless holds for hilly or mountainous territory throughout the United States.

This story, which I hope has illustrated for you the close interdependence which exists among some living things, is just one of scores that could be told. It is probably only one of hundreds that are yet to be discovered. If we are going to continue to live with nature in peace and safety to ourselves, this fact must ever be kept in mind. We need to return to an attitude of deep respect toward nature. The relationships which have been set up through the ages between wild birds, mammals and plants, in fact among all forms of life, can not be disturbed unless we are willing to accept the consequences—and these may be exceedingly serious for us. Where change in existing conditions appears to be unavoidable we should proceed with a caution befitting our inadequate knowledge of the forces with which we deal; and above all we should avoid the captious heedlessness that has characterized our exploitation of our surroundings so often in the recent past.

FOODS WE EAT AND WHY WE EAT THEM

By Professor R. ADAMS DUTCHER

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AT the Pennsylvania State College we have a student dining room which the architect has designed as a Pennsylvania Dutch grill. Over the counter from which the foods are served there is inscribed in German script the Pennsylvania Dutch motto, "Sak mir was du esscht und Ich sak dir was du bisscht." This is the Pennsylvania Dutch equivalent for the old maxim, "Tell me what you eat and I will tell you what you are." A recent writer has paraphrased this maxim by saying, "Tell me what you eat and I'll tell you how old you are." He informs us that it is possible to divide the span of human life into eleven dietary or gastronomic ages, which fall in the following chronological order:

Age No. 1—Milk.
" " 2—Bread and milk.
" " 3—Milk, eggs, bread and spinach.
" " 4—Oat meal, bread and butter, green apples and all day suckers.
" " 5—Ice cream soda and hot dogs.
" " 6—Minute steak, fried potatoes, coffee and apple pie.
" " 7—Bouillon, roast duck, scalloped potatoes, French rolls, creamed broccoli, fruit salad, divinity fudge and demi tasse.
" " 8—Pate de foies gras, wiener schnitzel, potatoes parisienne, egg plant a l'opera, demi tasse and Roquefort cheese.
" " 9—Soft boiled eggs, toast and milk.
" " 10—Crackers and milk.
" " 11—Milk.

While it is clear that this writer was poking fun at our dietary inconsistencies, he was also emphasizing a very important dietary truth, *viz.*, that milk plays a very important part in giving us the proper start in life and that we instinctively revert to milk when we have reached the age when our digestive organs begin to show the results of unwise dietary excesses of former years.

Our knowledge of foods and food values has undergone many changes as a result of chemical and nutritional researches. Hippocrates (460–370 B.C.) believed that there were many kinds of food but that there was but one single substance in foods which was necessary for normal growth and development. As late as 1813 the eminent French physiologist, Richerand, still adhered to this hypothesis. Twenty years later (1833) Dr. William Beaumont published his classical work on gastric digestion and at that late date he referred to the nutritive value of foods in terms of a

single substance which he called "aliment." It would be very easy to solve our dietary problems if this theory could be shown to be correct. Unfortunately for the layman, each new discovery in food chemistry seems to make the problem more complex.

Dr. William Prout, an English physician, was one of the first scientists to "complicate the picture" when he announced in 1834 that foods contain at least three essential types of materials which are necessary for good nutrition. These substances were called albuminosa, oleosa and saccharosa, which are known to us as proteins, fats and carbohydrates.

Justus von Liebig, of Germany, was largely responsible for the conception that fats and carbohydrates are used largely as sources of heat and energy in the animal body, while proteins function primarily as building materials for body tissues.

As chemistry developed, foods were classified according to their content of these three substances, and the first feeding standards for humans and domestic animals were, naturally, chemical standards. The first period, therefore, might well be called the "chemical period" in nutrition. This was followed by a second period, which might be called the "energy period," in which food values were expressed in terms of calories or heat units. It was not long, however, before it became evident that diets could be compounded from chemically purified proteins, fats, carbohydrates and mineral salts, which conformed to the best of the chemical and energy feeding standards and yet lacked something necessary for normal growth and reproduction.

A new method of research was devised, using chemically purified diets and small experimental animals, with the result that a new (biological response) period came into existence. This period of research has led to what is popularly called the "Newer Knowledge of Nutrition." During this period three important types of discoveries were made, which have had considerable influence on the food habits of the American people.

Prior to this period chemists and nutritionists believed that all proteins, regardless of source, possessed the same nutritive value because they all contained about the same amount of nitrogen. The new work with small animals proved that this is not the case, since animals grow better on some proteins than they do on others. Subsequent investigations by the ever curious research chemist led to the discovery that proteins of high biological value contained many amino-acids (which act as building stones for body tissues), while the poorer proteins were found to be lacking in some of these amino-acids which were needed by the body tissues.

When the missing amino-acids were added to the inferior proteins or when other proteins were added to the diet, rats again grew normally. Thus, the first important lesson to be learned is that, as a class, individual animal proteins are nutritionally superior to individual vegetable proteins and that the wise mother will plan her meals in such a manner that her growing children will be certain to receive all the amino-acids necessary for the construction and repair of muscles and similar tissues. This can be done by supplementing the important energy-producing foods, such as bread and cereals with vegetables, milk, eggs and meat.

The second discovery that resulted from work with small animals had to do with the mineral salts in the diet. Scientists already knew, of course, that the growing child and even mature people must have mineral salts in order to construct strong bones and teeth and keep the blood and body fluids in healthy condition. They had the feeling, however, that the mineral problem "sort of took care of itself" if the other ingredients, such as proteins, fats and carbohydrates, were provided in ample amounts.

The biological response tests with small animals soon exploded this idea, for it

was found that some of our daily diets were woefully lacking in certain mineral or inorganic salts. This type of research also led to a better understanding of the individual functions of the common inorganic elements, such as calcium, phosphorus, magnesium, sodium, iron and chlorine. Much to our surprise we began to discover that some of the rarer elements, such as copper, iodine, manganese and even zinc, might be vitally essential for health and well-being. In former years copper was considered a member of the "poison family"—to be gastronomically avoided. Biological tests have shown, however, that copper in traces has a very beneficial effect on the utilization of iron and helps us to build better red blood cells.

It is entirely possible that we may find eventually that practically all the inorganic elements have a definite function to perform, in spite of the fact that they are present in almost infinitesimal traces. Iodine is a case in point. When it is absent from the soil, food crops and waters—such as we find in goitrous regions—excellent prophylactic results can be obtained by eating foods or drinking water containing very small quantities of iodine. Again the conclusion seems inevitable—that we are more likely to obtain the mineral salts we need, if we will vary our diet sufficiently to ensure a varied supply of mineral elements.

I have already pointed out that milk contains proteins of high nutritive value. Milk also contains a very desirable mixture of inorganic salts. In fact, milk is our best single source of calcium, and research has shown that it is quite difficult for the growing child to obtain its daily calcium requirement unless it receives from a pint to a quart of milk daily. It is not necessary to drink this amount of liquid milk to obtain this amount of calcium. It is possible to ingest a portion of the milk as dried or evaporated milk in cooked foods, puddings, etc. The vegetables, particularly the leafy vegetables, also contribute appreciable amounts of calcium and other valuable mineral elements, such as iron. Thus we have learned to drink more milk and eat more vegetables and fruits in order that our mineral salt supply may be adequate for normal health and well-being.

A third discovery that developed from animal experimentation was even more unexpected and unbelievable, *viz.*, the discovery of vitamins. It was found that some foods did not contain these mysterious chemical substances and if these foods were fed for long periods of time (without supplementation with other foods) animals ceased to grow, failed to reproduce and developed disease symptoms identical with or similar to human diseases that have been known by the medical profession for centuries. It was soon possible to produce experimental dietary diseases similar to if not identical with human beriberi, pellagra, rickets and scurvy. Then discoveries came so fast that even the research workers themselves had difficulty keeping up with the newest developments.

Vitamin A received considerable front page publicity because its absence from the diet caused loss of weight, respiratory diseases and blindness in rats, which could be prevented when milk, butter fat, egg yolk, fish liver oils, carrots or pigmented leafy plants were added to the diet. The world war presented an opportunity to test the value of rat experiments on humans because children in Rumania and Denmark were deprived of dairy products which resulted in pathological eye symptoms similar to those produced in vitamin A-deficient rats. When Denmark discovered that she was selling her milk and butter at the expense of the health of her children, she eliminated the eye disease by regulating the amount of dairy products that could be shipped from the country. In Rumania the problem was solved by administering cod liver oil to all children.

Brilliant researches of the past few years have shown that the yellow pig-

ment carotene, found in carrots and many plants, can be changed into vitamin A by the body tissues. The cow takes this pigment from her feed, changes a portion of it into colorless vitamin A and excretes the excess of yellow pigment in the milk, where it is available for us to transform it to vitamin A in our own tissues. Guernsey and Jersey cows can not change this pigment into colorless vitamin A quite so readily as the Holstein and Ayrshire breeds, with the result that butter fat from the former is more yellow than that from the latter, but the total biological values (from the standpoint of carotene and vitamin A) are equal, the former being richer in the provitamin, carotene, but poorer in colorless vitamin A. The reverse is true for Holstein and Ayrshire butter fats, since they contain more of the colorless vitamin A but less of the yellow carotene. Since Guernsey and Jersey milks usually contain higher percentages of butter fat, the total vitamin A effect of the milk may exceed that of the non-pigmented breeds. These are no longer mysterious substances, for we are now able to write the chemical formulae for vitamin A and for carotene.

Vitamin B or B_1 (anti-beriberi vitamin) has now been crystallized and its chemical formula is practically assured. This vitamin is necessary for normal health, appetite and growth and is found in cereals, yeast, milk, leafy vegetables and fruits.

Vitamin C is now being manufactured artificially by the pound, its chemical structure has been determined and the chemist calls it ascorbic acid. When we eat liberal amounts of oranges, lemons, tomatoes, fresh cabbage, lettuce and similar foods we are certain to obtain sufficient quantities of this scurvy-preventing vitamin.

An artificial type of vitamin D (known as activated ergosterol) has also been crystallized. It has been obtained in pure form and its chemical formula is known with a fair degree of certainty. This rickets-preventing vitamin is necessary for the proper building of bones and teeth in growing children. Our best natural sources are the fish liver oils. Milk does not contain it in satisfactory amounts, as a rule, which accounts for the fact that we find various types of vitamin D milk on sale which have been supplemented with various forms of vitamin D.

Vitamin E, the fertility or anti-sterility factor, will not be discussed because its clinical importance has not yet been fully established.

Vitamin G or B_2 promotes appetite and well-being. Without it a number of pathological conditions develop of which a pellagra-like skin disease is the most outstanding. We find this vitamin in many foods, such as yeast, whole cereals, milk, vegetables and fruits. Investigations of the past few months indicate that vitamin G (B_2) consists of two separate substances. One of these is a yellow pigment called "flavine" which is thought to be necessary for growth. The other fraction, tentatively called vitamin B_6, is thought to be specific in preventing and curing a dietary dermatitis in rats which is similar to pellagra in human beings. A number of other "B vitamins" have been suggested, but we have no information to date that they have any importance in human nutrition.

The newer knowledge of nutrition has taught us to be reasonably careful to supplement our daily diet of meat, bread and potatoes with the "protective foods," such as milk, eggs, fruits and vegetables. It is unwise and unscientific to condemn wholesome foods merely because they are lacking in certain dietary essentials. It is much safer and more economical from a health standpoint to supplement such foods with reasonable amounts of milk, eggs, vegetables and fruits.

EXCAVATION OF CRETACEOUS REPTILES IN ALABAMA[1]

By Dr. J. J. RENGER

SPECIAL ASSISTANT IN PALEONTOLOGY, GEOLOGICAL SURVEY OF ALABAMA

DURING the summer of 1933 there were found and excavated in Alabama two very fine and representative specimens of the upper Cretaceous Era. The first find was that of a giant marine *Protostega* turtle, and the second find was the terror of the Cretaceous seas, an unusually large *Mosasaurus*.

The first find was made near Eutaw, and the second find was near West Greene, both in Greene County. The stratum in which the fossils were found has been established by Dr. Walter B. Jones, state geologist, as the uppermost portion of the Selma formation of upper Cretaceous age. The layer at the place in which the excavations were made consisted of rotten limestone with a superimposed layer of drift or second bottom of the river. The turtle was found at a depth of six feet below the top-soil, on a washed spot, which from the numerous fossils found must have been a veritable cemetery of Cretaceous animals. The *Mosasaurus* was more propitiously located near the surface of the soil.

It is fortunate that both these animals were found, as they represent the most highly specialized aquatic forms of the era. They were also the most ferocious aquatic animals of the Cretaceous sea and were in most parts implacable enemies. On the bones of the turtle the evidence of the teeth marks of the carnivorous *Mosasaurus* show clearly that the animal either succumbed in a fight or was the prey after its natural death.

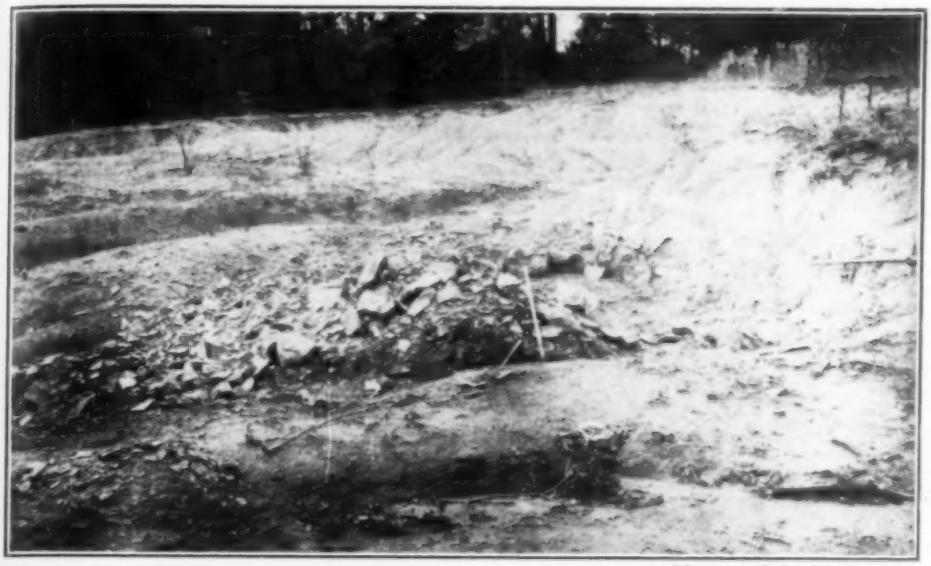
After the remains of the animal sank into the ooze at the bottom of the sea, and more sedimentary material fell on it, the bones of the turtle suffered breakage before petrifaction set in, and also further breakage and re-cementation after the fossils had been formed.

The fossils, after being repaired, assembled and restored, were identified by the writer as belonging to the order of reptiles known as *Chelonia* or *Testudinata*, and to the ancient family of sea turtles, *Protostegidae*.

No order of animals, that has persisted to this day, has a longer and more uneventful history than the order of *Chelonia;* and of none is the origin more obscure. If the turtles were not so familiar to us, or were entirely extinct as are nearly all the forms of life of that period, they would be considered the strangest of reptiles, and perhaps the strangest of vertebrates. It is the only animal that can hide its head and limbs under its ribs. The carapace or shell of the turtle is nothing more than the backbone and the dorsal and ventral ribs flattened and expanded and covered on the outside with heavy skin plates.

The evolution of the shell of the sea turtles is a progressive reduction of the bones of the carapace in adaptation to aquatic life. As the *Chelonia* of the Mesozoic Era reverted to water as their habitat, the need for a protective armor was less necessary than for those which remained on land; therefore, the continuous bony cover tended to disappear at the ribs and progressively receded toward the backbone. The *Protostegidae* is therefore a type that has been developed long after the turtles returned to the sea, as the greater part of the cara-

[1] Published by permission of the Geological Survey of Alabama.



Photograph by W. B. Jones

FIG. 1. EXCAVATING FOSSIL TURTLE NEAR EUTAW.

ABOUT TWO THIRDS OF THE ANIMAL HAD BEEN TAKEN OUT AT THE TIME THIS PHOTOGRAPH WAS TAKEN. THE HILLOCK AT THE LEFT FOREGROUND IS A BADLY BROKEN SPECIMEN OF NAUTILUS, *Pachydiscus Sp.*, SOME 30 INCHES IN DIAMETER.

pace and of the plastron are lost in this family. Also, the ribs are considerably flattened and consequently the usually greatly concave shell is depressed, a feature which aided in the aquatic forms and is another adaption to a sea life.

The modern leatherback turtle, a modification of the ancient sea turtle, in exceptional cases, attains the length of six feet. This size is only half that of the size of the specialized giant among the turtles of the upper Cretaceous.

The measurements of some of the parts can best give a good picture of the turtle. The humerus or upper arm of the animal is 42 cm long; the radius is 25½ cm; the metacarpals and carpals, or wrist bones, are 14 cm; and the length of the finger bones and talons is 51 cm, making the total length of the outstretched front flipper 132 cm, or 4 feet and 4 inches. The span between the tips of the front flippers is 3 meters, or 9 feet and 10 inches. The length of the shell along the median line is nearly 5 feet. This animal, which had a flipper spread of nearly 10 feet, weighed about two and one half to three tons in its live state. It also had a formidable head, nearly 20 inches long, and equipped with an overhanging beak, six inches long and four inches wide.

The anatomical features of the giant turtle are very interesting, and from them several conjectures as to the animal's existence and mode of living can readily be deduced. The most conspicuous feature of the limbs is the size of the front flipper. The humerus is long and massive. The five digits are unusually long and supplied with strong long claws. Unlike all other aquatic vertebrates the turtles never developed real hyperphalangy. Naturally, the fingers were webbed; and, with the ectocondyle or muscle-attachment on the humerus, far down the shaft, it gave the *Proto-*

stega an oar-like organ for greater mechanical advantage in swimming. The flatness of the humerus and also the lowness of the radial crest and the expansive spread of the digits shows conclusively the adaptation to marine life. Although the turtle had great weight and a shape which was not very conducive to fast swimming, yet the indication of great musculature compensated for the bulk; and it must be assumed that the animal was a powerful and relatively fast swimmer. The rear flippers are smaller than the front and played a less important part in the locomotion of the *Protostega*, serving wholly as steering apparatus.

It is also a certain conjecture from the physiological processes of marine turtles, and from the fact that the remains of ancient turtles are found, as in this case, always in deposits which indicate shallow waters, that this type of turtle was a bottom-feeder and a littoral inhabitant.

The jaws with the massive premaxilla and the broad mandible were not only a good weapon of defense, but suggest an adept crusher of crustacea and mollusca. The abundance of shell-fish of that period afforded an almost inexhaustible source of food for the large turtle. The premaxilla is in the shape of a curved beak; such a feature would easily transform even a sluggish animal into a most formidable enemy.

In addition to the quality of a powerful swimmer, and an adequate defensive beak, the gigantic marine turtle had a protective carapace and plastron into which it could always withdraw its limbs and even partially the neck. Thus in the fight for existence the *Protostega* was well equipped to survive. In some battles the turtle may have lost a limb when very young; yet not be unable to survive and perhaps come out the victor over the *Mosasaurus*, the dread of the period. Dr. Wieland's "Archelon," a turtle 10 feet in diameter, is a classical example of the occurrence of such a battle and the

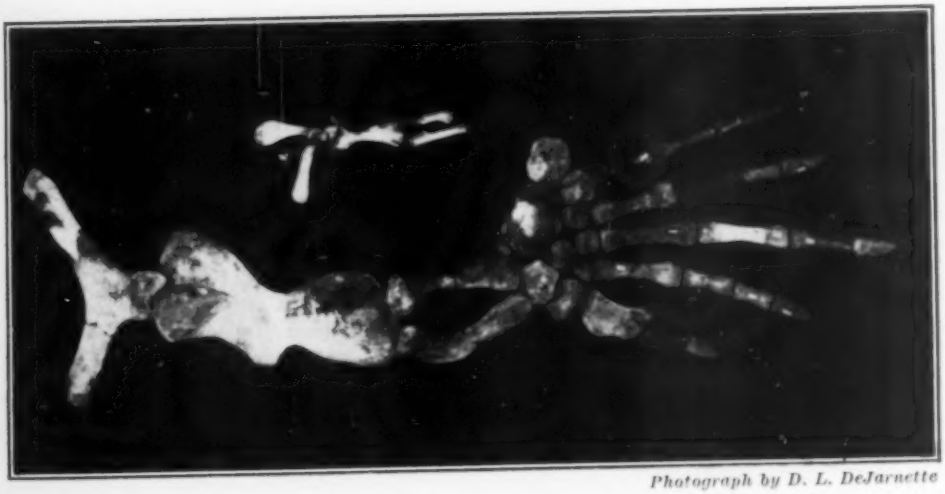
Photograph by W. B. Jones

FIG. 2. OCCURRENCE OF THE *MOSASAURUS* NEAR WEST GREENE. THE MAXIMUM COVER IS APPROXIMATELY SIX FEET.

Photograph by W. B. Jones

FIG. 3. THE JAWS AND SKULL

OF THE *Mosasaurus* BOXED AND READY FOR LOADING. THE JAWS EXTEND FROM CORNER TO CORNER.



Photograph by D. L. DeJarnette

FIG. 4. BONES OF RIGHT FRONT FLIPPER OF FOSSIL TURTLE

WITH COMPARATIVE BONES TAKEN FROM 140 POUND RECENT FRESH WATER TURTLE.

Photograph by D. L. DeJarnette

FIG. 5. PARTIALLY RESTORED UPPER JAW OF *MOSASAURUS*
SHOWING MASSIVE STRUCTURE OF JAW AND HEAVY TEETH.

turtle's survival after the loss of the rear right flipper.

In the classification of the fossils, it became apparent that the present specimen does not satisfactorily conform to all the genus characteristics of the *Protostega*, to which the specimen shows closest resemblance, nor do the ratios of the parts conform to the genus *Archelon*. The family is clearly established by the ribs forming the carapace, but the genus is still somewhat doubtful. Perhaps after full restoration of the skull is effected, the genus can be determined, which may also show it to be a new species.

In all events the present specimen is by far the largest fossil turtle of that type yet found, and is exceeded in size by only one specimen of a closely related form, that of the *Archelon ischyros Wieland* in the Yale Museum.

The *Mosasauridae* fossils, found in the same geological stratum, are of unusual interest to paleontology because of the singular anatomical structure of the head. The *Mosasaurus* is a short-necked marine lizard that lived in the shallow seas of the great chalk age, where it undoubtedly reigned supreme by virtue of its size and its ferocious and powerful jaws.

The head of the specimen found measures five feet, and the jaws comprise three fourths that length. The skull of this animal is about one sixth of the entire length. The relative size of the head to the body is indicative of predaceous and pugnacious habits of this sea lizard. It also indicates that the present skeleton is at least thirty-five feet long.

The upper and lower jaws are provided with numerous sharp conical teeth. Besides these there are also two rows of strong teeth implanted in the back part of the palate, on the pterygoidal bone; these are the throat teeth and are of great significance to the animal's feeding problem. The unique feature of the *Mosasaurus* is the conspicuous ball-and-socket joint in the middle of the lower jaw which permitted lateral flexing of the lower jaw. In this respect the mosasaur differs from all other reptiles, ancient or modern.

Besides the joint in the lower jaws, the tip of the lower jaws, at the point of symphyses, was loosely connected with ligaments. This flexibility was essential to the existence of this animal; for without any prehensible limbs, as in the modern lizards, nor with teeth adapted to tearing its prey apart, the mosasaur had to swallow its food whole.

The method of deglutition was very unique. The mosasaur seized its prey between the jaws, then extended the lower jaw by bending it laterally at the joint at the end of the splenial bone, and renewing its bite on the prey with the posterior teeth. By repeating this process the animal steadily pushed the food far enough back to be seized by the muscles of the fauces and the throat teeth.

Like all ancestral stock of the lizards the mosasaur had a pineal opening in the skull, but it is questionable whether it had a functional third eye, as in the *Rhyncocephlia* of to-day.

The paddle-like limbs of the mosasaur were adapted for aquatic life only. It may have moved in a serpentine way when accidentally stranded or while laying its eggs on the shore.

The assembled limbs of the turtle are now on exhibit in the Alabama Museum of Natural History, University, Alabama; and the skull of the mosasaur is in the process of reconstruction (see Figs. 4 and 5). Of the mosasaur, only seventeen feet of the skeleton have been removed so far, and the remaining part will, it is hoped, be removed soon.

Pach Brothers

HENRY FAIRFIELD OSBORN

THE PROGRESS OF SCIENCE

HENRY FAIRFIELD OSBORN: AN APPRECIATION

HENRY FAIRFIELD OSBORN, honorary president of the American Museum of Natural History, died "in harness" on Wednesday, November 6, 1935, at the age of seventy-eight years. He was reading his morning mail in his study at "Castle Rock," Garrison-on-Hudson, N. Y., and was preparing to put in another joyous day's work on the second volume of his monograph on the fossil Proboscidea, when, as his son said, "he just fell asleep." Thus an ideally quiet and peaceful ending came to a life which combined an amazing activity with unperturbed quietness and dignity.

His fifty-eight years of "research, observation and publication" left a deposit of some 940 published communications, ranging from brief articles to voluminous monographs; he dictated tens of thousands of letters and wrote by hand hundreds of others. In the numerous organizations in the development of which he was actively interested he was seldom long unheard.

The most important of his scientific writings were in the field of vertebrate paleontology, but the principles of evolution, the prehistory of man, the biography of great naturalists, eugenics and educational methods and ideals were always in or near the front rank of his teeming mind. His effect on other people was in general highly dynamic and in one way or another he directed, encouraged or materially aided a great many investigations, publications, exhibits or courses of instruction prepared by others.

During the course of his long career he was instructor and later professor of comparative anatomy at Princeton University, Da Costa professor of zoology and dean of the Faculty of Pure Science at Columbia University, founder, curator and honorary curator of the department of vertebrate paleontology at the American Museum of Natural History, and later president of that Museum. He was perhaps the leading spirit in the foundation of the New York Zoological Society and served for many years as chairman of its executive committee and later as its president. In Princeton, long after he had removed to New York, he was influential in many projects, notably the building of the new museum of geology and paleontology.

At the museum for a quarter of a century he presided easily and securely over a board of trustees that included such veritable giants as J. P. Morgan, Joseph H. Choate, George F. Baker and Cleveland H. Dodge.

In honor of Theodore Roosevelt, who was his boyhood companion and lifelong friend, Osborn, with somewhat of Aladdin's magic, conjured forth a huge memorial building of surpassing dignity and beauty.

The Museum of Natural History under his leadership added many great buildings to itself, nearly doubling its capacity, and filled its granaries almost to the bursting point with the plenteous harvest reaped by its naturalists and explorers.

The Royal Society of London welcomed him as a foreign member and so did a long series of other leading scientific societies in Europe, China, India, the United States, Mexico and South America. To him were awarded many beautiful gold medals and coveted prizes: the Darwin medal of the Royal Society of London, the Wollaston medal of the Geological Society of London, the *Prix Albert Gaudry* of the *Société géologique de France*, the medal of the Pasteur Institute of Paris, and many others abroad and at home. The oldest universities in

England and Scotland vied with the universities of his own country in bestowing upon him their highest honorary degrees.

Castle Rock was almost as important a center as the museum for the radiation of his influence. There he constantly entertained men of distinction from all parts of the world and the names inscribed in the Visitors' Book would be a roster of international science, art, philosophy and statesmanship for two generations. When the meeting of the International Congress of Zoology was held in New York, Professor Osborn chartered a river boat, took the entire congress up the river to Garrison, and with his brilliant wife, Lucretia Perry Osborn, entertained his guests at a memorable luncheon party at Castle Rock.

Now what manner of man was this, who governed so easily and maintained such a multitude of contacts and could yet find time to produce a prodigious mass of scientific and educational writings? How did he come by his power and serenity, his dignity, his benevolence, his steadfastness, his good humor, his quiet friendliness? Let it be admitted that even the lowest human intelligence is too complex to be accounted for historically, and that the growth of each self is a unique integration of actions and reactions to hereditary, physiological and environmental stimuli which it is difficult or impossible to untangle. Nevertheless, there are abundant historical data which at least indicate some of the leading influences to which Henry Fairfield Osborn in the course of his own development reacted as he did.

His father, William Henry Osborn, was a man of preeminent probity and ability, who reorganized and built up a great railroad system. A small incident related to me by Professor Osborn will perhaps serve to illustrate his father's quick resourcefulness. On one occasion when William Henry Osborn was returning from Europe the ship was held up so long at quarantine that he would almost inevitably be prevented from rejoining his family on Christmas eve. He therefore went below, borrowed an old hat, picked up a mail bag and threw it over his shoulders and walked to freedom down the plank to the mail-boat. The elder Osborn evidently had a sincere admiration for the grand manner in nature, in art and in architecture, for his friend, the famous artist F. S. Church, painted for him a great canvas of mountain scenery in the Andes and selected for him the exact spot in the highlands of the Hudson upon which he built the tower of Castle Rock. And from the wide stone platform there one can look outward upon a view of astonishing magnitude and sweep, with the broad curving river beneath and the granite mass of Storm King beyond.

Professor Osborn's mother, as I remember her, might almost have sat as the original of Whistler's famous portrait of his mother. She combined gentleness and quietness with firmness. She was untiring in good works and was the chief founder of the Virginia Day Nursery.

At Princeton the young Osborn was greatly influenced by Dr. McCosh. This remarkable man, who combined the Presbyterian religion and philosophy with a dry Scotch humor, was one of the first orthodox clergymen to accept the principle of evolution; he therefore actively encouraged the development of the departments of geology and biology. Under Dr. McCosh, Osborn began a series of studies upon the visualizing faculty of the mind, but this interest in introspective psychology soon led him to studies bearing on the evolution of the nervous system in the lower vertebrates. Probably it was from his more or less Calvinistic environment that Osborn derived that deep antipathy to the idea of fortuity or chance, which was to remain as an outstanding characteristic of his philosophy of evolution and made it im-

possible for him to accept natural selection in its Darwinian form.

Meanwhile the fame of the discoveries by Professor Marsh, of Yale University, and Professor Cope, of Philadelphia, of many gigantic extinct forms of animals in the great natural cemeteries of the West doubtless excited at Princeton not only keen interest but the spirit of emulation. Accordingly, the young Osborn, with his friend W. B. Scott and several others, under the general direction of Professor Guyot, conducted the Princeton Scientific Expedition of 1877 to the Bridger and Washakie Basins in Wyoming. This was the first of those great expeditions which both Scott and Osborn were destined to send out during the next half century. The year following the expedition (1878) was taken up in part by the working out of the fossils from their hard matrix and by the identification and description of the material.

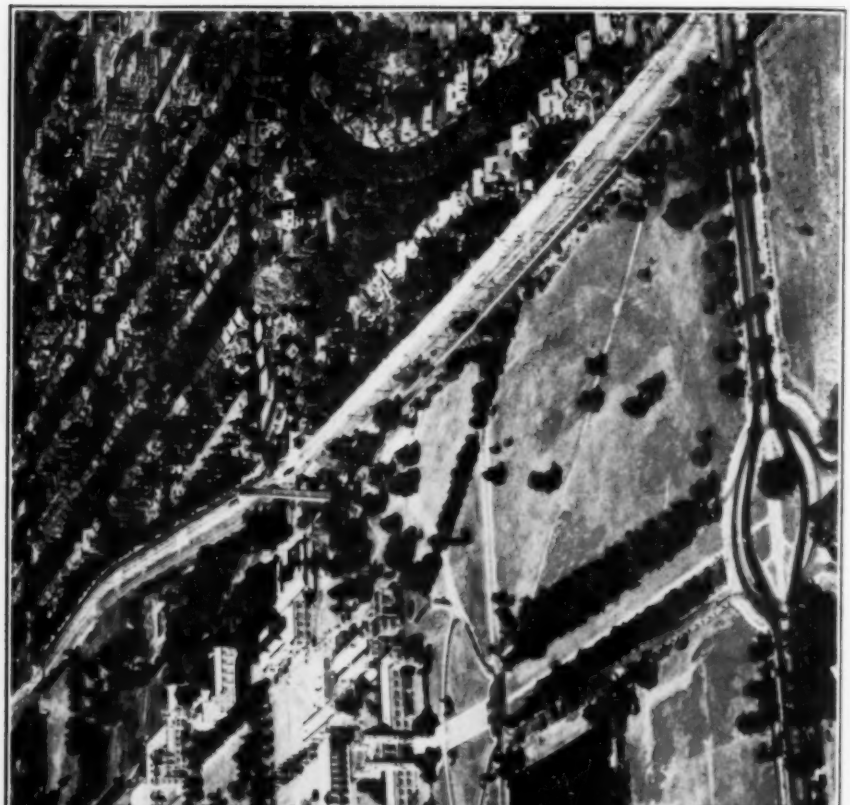
Doubtless at this time the two friends, Osborn and Scott, came to realize how meager was their equipment for satisfactory progress in either comparative anatomy or paleontology. In any case they wisely decided to study in Europe, Scott chiefly in Germany, Osborn in England.

Arriving in England in 1879 and entering Cambridge University for graduate study in zoology, Osborn found himself at the very source of many of the influences which he had felt in his home across the ocean. For now he was studying embryology at Cambridge under the direction of Francis Maitland Balfour; a little later at the Royal College of Science in London he attended the famous Huxley's lectures on comparative anatomy. One day Darwin himself came in to the laboratory and Huxley singled out the modest American youth, introduced him to the gentle and venerable Darwin and spoke of Osborn's promising work in the American Eocene. Soon afterward Osborn met Francis Galton and perhaps derived partly from him the springs of his later keen interest in human heredity and eugenics, for he collaborated with Galton in a paper, "Questions upon the Visualizing and Other Allied Faculties," and wrote a review of Galton's "Record of Family Faculties" when it was published in 1884.

Other important friendships for which he laid the foundations during his early days in England were those with Edward Poulton, of Oxford, with the Huxley family and with Leonard Darwin. The Princeton of 1877, in so far as it was dominated by Americans of English and Scotch descent, was practically an outpost of British culture and his own ancestry and upbringing predisposed him to appreciate and respond to the potent and ennobling ideals of the great Victorians.

But something more than all this contributed to his triumphal drive, continued for more than half a century and leading to wider and wider activities of organization, construction, administration and to scientific investigation, publication and education on a vast scale. Part of that something was his tireless and highly successful wife, Lucretia Perry Osborn, who was always his most ardent admirer and energetic partner. It was she also who sustained his spirit during periods of opposition and discouragement, and her death in 1930 deprived him of a powerful support. At the same time perhaps it intensified his passionate belief in the reality both of "creative evolution" and of the most essential features of modern Christianity. These he had derived from the days of his youth, and in all his writings on evolution, education and religion they are set forth with clearness and conviction. Doubtless his philosophy will be evaluated differently by those who view it from opposite poles; but it is clearly incumbent upon a student of his life history to set forth his philosophy along with his science.

William K. Gregory



AERIAL VIEW OF THE MAIN CAMPUS OF WASHINGTON UNIVERSITY

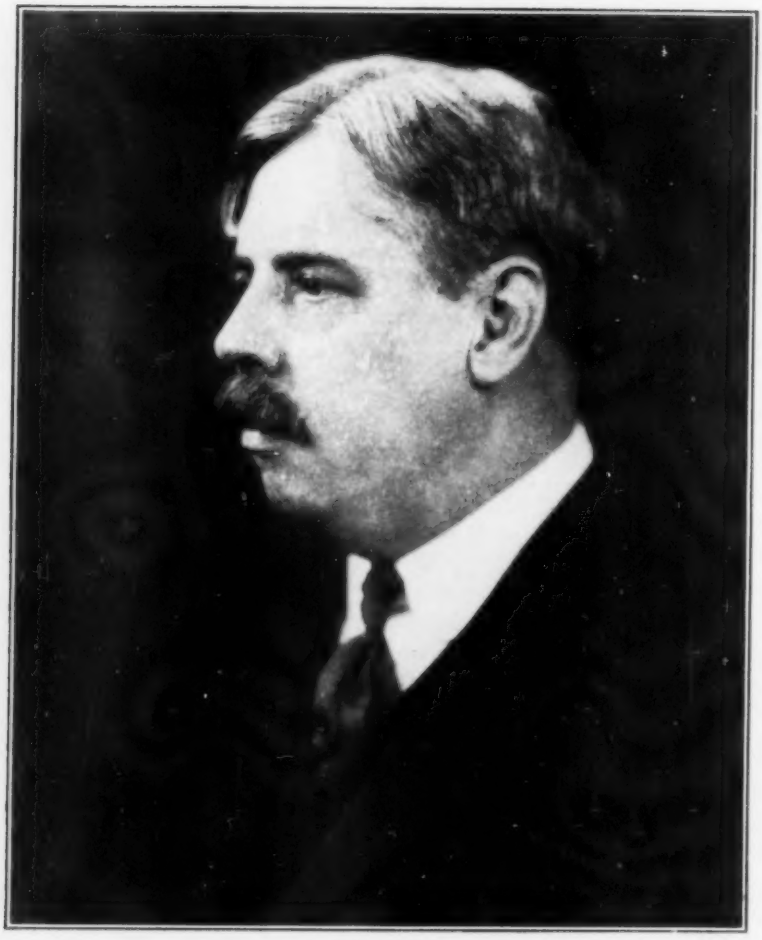
THE ST. LOUIS MEETING OF THE AMERICAN ASSOCIATION

THOSE who attended the last meeting of the American Association for the Advancement of Science, held in St. Louis some sixteen years ago, will, it is hoped, come again this year, if only to note the changes and improvements that have taken place. The conduct and programs of the meetings have improved progressively since 1919, and the prospects for the coming sessions are better than ever before. With the new Municipal Auditorium, St. Louis is now able to provide suitable accommodations for the special evening programs as well as various daily sessions, which were not possible even a few years ago. New buildings at St. Louis University and Washington University which will be used combine convenience and comfort to an extent which it is hoped will eliminate all recollection of the congestion and confusion that could not be avoided before they were available. The down-town hotels are in easy walking distance from the Auditorium, where registration will take place. The up-town hotels, headquarters for those using the two universities, are either close by or can easily be reached by car or bus.

This is not the place to discuss the program in detail. Preliminary notices in *Science* will list some of the outstanding features, and the final printed program will, as usual, give a full and complete account of the general and special sessions. At this time it can safely be predicted that the meetings will be outstanding, both because of the subjects discussed and the men who will participate. The mere mention of such outstanding speakers as Professor E. L. Thorndike, the retiring president, Dr. Karl F. Meyer, of the Hooper Foundation, San Francisco, Dr. Stanhope Bayne-Jones, of Yale, Dr. F. J. E. Woodbridge, of Columbia University, Professor Frederick Slocum, of Wesleyan University, Professor Vannevar Bush, of the Massachusetts Institute of Technology, Professor V. O. Knudsen, University of California at Los Angeles, Dr. J. B. Taylor, of the General Electric Company, Dr. E. H. Barbour, of the University of Nebraska, Dr. V. K. Zworykin, of the RKO Victor Company, Dr. H. G. Moulton, of the Brookings Institution, with a host of others, is sufficient guarantee of the high character of the meetings, as well as the universal appeal to all interested in science with its innumerable ramifications.

Aside from the general sessions and the meetings of sections and societies, a main attraction should be the scientific exhibits. These will be located in the Auditorium, with much more space available than is usually the case. Each year since the inception of these exhibits has shown an increased attendance and interest. Those not located in one of the large scientific centers are beginning to realize that on such an occasion an opportunity is afforded them to inspect and become familiar with apparatus and instruments of every kind; that books and supplies can be examined at first hand and the very latest advances in laboratory equipment are presented, with experts on hand to explain and demonstrate them. Quite apart from what may be regarded as the commercial side of the exhibition, there will be many special set-ups illustrating the advance in science in every field. Not only for the specialist but for the lay mind as well, many of these exhibits will prove of great interest.

For those who do not care to spend all day attending meetings St. Louis offers special attractions, some of which are not available elsewhere. The Jefferson Memorial not only houses some of the largest and most complete collections pertaining to historical events in the Mississippi Valley, but here are to be found the famous Lindbergh trophies; gifts, medals and souvenirs from thousands of sources, including a score of foreign countries.



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PROFESSOR EDWARD L. THORNDIKE,
RETIRING-PRESIDENT OF THE AMERICAN ASSOCIATION.

The Art Museum and the Zoo, each maintained as a civic enterprise through a mill tax, are located in Forest Park. This park, comprising some 1,400 acres, is one of the largest and most beautiful in America. Here in the summer season ten thousand people are able to enjoy each evening light opera in the unique municipal open-air theater.

St. Louis and Washington Universities, with their various schools and hospitals, need no special notice. They will both be used for meetings, and interested visitors will have ample opportunity to inspect them.

The principal attraction at the Missouri Botanical Garden will be a special orchid show staged for the occasion. The Garden possesses one of the largest collections of orchids to be found in any institution of its type. Some thirty thousand plants are housed at the Gray Summit Arboretum, a 1,600-acre tract now being developed. Blooming orchids are transported thirty-five miles from there to the floral display house in the Garden in St. Louis throughout the blooming season. While during the time of the meetings there will be nothing of interest to see out of doors, the various collections of palms, tropical plants, desert plants, etc., under glass, are always attractive.

With a splendid scientific program,

Photograph by Bachrach

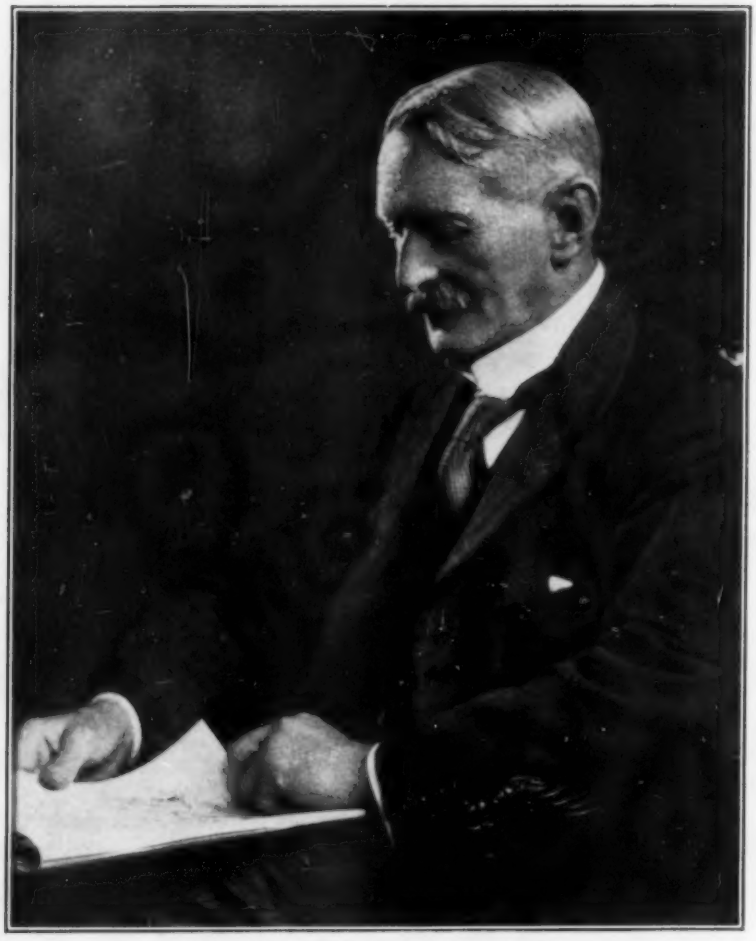
DR. KARL T. COMPTON,
PRESIDENT OF THE AMERICAN ASSOCIATION.

marked by outstanding contributors to the general sessions, and a complete scientific exhibit shown under adequate conditions, the success of the St. Louis meeting is assured. The added attractions of the city itself, with something to appeal to the most varied interest, should insure a record attendance. No effort will be spared by those in charge to make the St. Louis meeting of the association long and favorably remembered.

GEORGE T. MOORE, *Director*
MISSOURI BOTANICAL GARDEN

THE BRITISH ASSOCIATION AT NORWICH

THE meeting of the British Association which was held in Norwich from the 4th to the 11th of September last was by common consent no less successful and enjoyable than usual. There had been no previous meeting of the association in Norwich since 1868, and there was therefore little in the way of local experience to draw upon; but the association supplies its own precedents, and all the arrangements made by the local committees were admirable. The attendance of



PROFESSOR W. W. WATTS, F.R.S.,
PRESIDENT OF THE BRITISH ASSOCIATION.

members reached the number of 2,320, which was accounted satisfactory: it is only in larger cities, and in those possessing universities, that much larger attendances are to be expected. For the rest, there could scarcely be a more attractive center and area for a meeting of the association than that provided by Norwich and by East Anglia, of which Norwich is the ancient capital. The whole district is replete with scientific interest, in geology, geography, prehistoric archeology, botany, zoology, agriculture and other departments; and full advantage was taken by the sections interested in these subjects to make excursions and carry out field work. The city itself is historically one of the most interesting in all England, and members of the association freely availed themselves of opportunities for relaxation from scientific work by committing themselves to the expert guidance of local authorities who were at hand to show them many of the fine old buildings which Norwich possesses. The headquarters of the association (known as the Reception Room, where ticket business and the like are done and a common rendezvous is provided) were in St. Andrew's Hall, which is in fact the former fifteenth-century church of the Black

SIR JOSIAH STAMP, G.C.B., G.B.E.,
PRESIDENT-ELECT OF THE BRITISH ASSOCIATION.

Friars, long desecrated, but most wisely preserved in modern times as a public hall. The civic reception given to the members by the Lord Mayor and Lady Mayoress (Mr. and Mrs. Jewson) took place in the stately Norman castle which dominates the city from its high mound; it is now a museum, and a very fine one, to the scientific interests of which due attention was paid. The official Church of England service, attended by principal officers of the association, was held in one of England's most beautiful ancient cathedrals. The association has not often such a setting as Norwich for its meetings.

At the inaugural meeting the president, Professor W. W. Watts, F.R.S., dealt in his address with the subject of form, drift and rhythm of the continents. He was supported on the platform by four past presidents of the association in Lord Rutherford, Sir Arthur Keith, Sir Thomas Holland and Sir James Jeans; but he had to refer to no less than four others who within the year since the previous meeting had been lost to the association: these were the late Sir Edward Sharpey-Schafer, Sir Arthur Schuster, Sir Horace Lamb and Sir Alfred Ewing. On other evenings during the meeting there were discourses by

Dr. S. J. Davies on Diesel engines in relation to coastwise shipping, and by Dr. C. S. Myers on the help of psychology in the choice of a career. Further, Norwich and East Anglia took advantage of a procedure which the council of the association is always ready to put into operation if called upon, namely, to appoint lecturers to address public audiences (not confined, that is, to members of the association), with the result that such lectures were given in Norwich itself and also in the neighboring towns of Cromer, Fakenham, Great Yarmouth, King's Lynn, Lowestoft and Thetford.

It is impossible to review within a few hundred words the whole of the sectional programs, with their three hundred addresses, discussions, lectures and papers. One aspect of general interest, however, is found in the increasingly strong demand by public opinion that the association should pay even more emphatic attention to the exposition of scientific developments which affect public welfare and social progress. This is an interesting and gratifying sign of the times. So well marked has this attitude toward the advancement of science now become, that the association was even upbraided in certain newspapers, after the meeting, for taking insufficient notice of it in drafting the programs. And yet among the sectional presidents' addresses there were Dr. J. A. Venn's on the financial and economic results of state control in agriculture; Professor G. Hickling's on recent research on coal; Professor J. G. Smith's on economic nationalism and foreign trade; Dr. A. W. Pickard-Cambridge's on education and freedom; Professor P. G. H. Boswell's on the preservation of sites of scientific interest in town and country planning. Among discussions and papers with a similar bearing there were a discussion on the herring problem, and others on economic aspects of diet, scientific management, television, the applications of science to the control of road traffic (in which engineers and psychologists made an unusual collaboration), hearing and aids to hearing and sugar-beet problems; and among demonstrations there were Dr. G. W. C. Kaye's experimental lecture on noise, one of industrial management films and one of physical education. It is not a bad record for one meeting. And the scientific interests of the community are not likely to be lost to sight next year, when the meeting will take place (from September 9 to 16) at Blackpool in Lancashire, one of the biggest places of public holiday resort in England, and when the president of the association will be Sir Josiah Stamp, G.C.B., G.B.E., an economist of international standing.

The centenary of Darwin's landing in the Galapagos Islands, which fell close to the time of the meeting, was duly celebrated by papers and a discussion on the birth of the hypothesis of the origin of species. The British Association, as is well known, has an honorable relationship with Darwin's memory through its possession of his house at Down, in Kent, which it acquired by the gift of Sir Buckston Browne, and maintains as a national memorial, open to the public. It was a happy incident of the Norwich meeting that during it the association received from Emeritus Professor Van Dyck one of the last letters (if not the last) written by Darwin, a few weeks before his death in 1882; this has now found an honored place in the collection at Down House. As for the Galapagos Islands, the association, with much satisfaction, received word of the intention of the Ecuadorian Government to create a nature reserve in the archipelago; the American efforts which have been made to this end are profoundly appreciated, and the association gave evidence of its willingness to lend any assistance within its power to the consummation of this most important scientific movement, by appointing representatives to cooperate with any committee which may be appointed on this side of the Atlantic in connection therewith.

O. J. R. Howarth,
Secretary.

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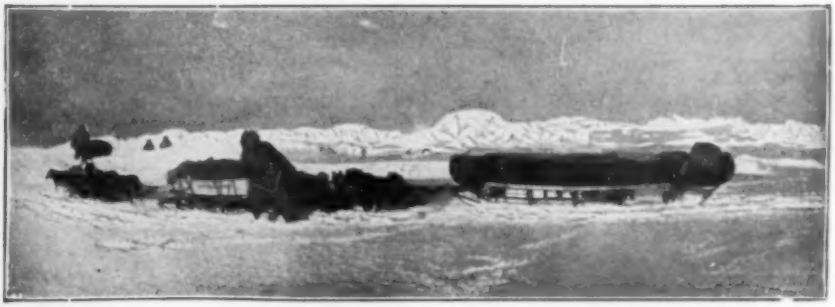

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